STUDY ON THE ESTIMATION OF THE VALUE OF LOST LOAD OF ELECTRICITY SUPPLY IN EUROPE

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EXECUTIVE SUMMARY

CEPA was commissioned by ACER to provide a study on the estimation of the Value of Lost Load (VoLL) of electricity supply in Europe. In this report, we present our findings.

In modern societies, the vast majority of economically productive activity depends, at least to some extent, on electricity. Though electricity is provided with a high degree of reliability across Europe, where disruptions do arise, this can result in very high costs to society. On the other hand, maintaining a high level of security of supply is costly, and no system can ever be 100% secure.

VoLL places a value on the loss of socio-economic activity which takes place when electricity is not provided to consumers. It is used to measure the marginal benefits of improving the level of security of electricity supply. The concept of VoLL has a number of potential regulatory applications, including:

- cost-benefit analyses for policy and infrastructure development;
- the design of regulatory incentives and compensation mechanisms;
- wholesale market design; and
- procurement of services to improve the level of security of supply.

VoLL is becoming an increasingly important concept in European electricity regulation and policy. The importance of measuring VoLL has increased as electricity markets in Europe have become increasingly liberalised, as the penetration of intermittent renewable generation has increased and as electricity networks are used more flexibly.

Methodological approach

We have used a consistent methodology to develop estimates of VoLL covering all consumer types and for all European Member States (MS) for the first time. We employed two supporting methodologies to achieve this.

Our headline VoLL estimates were developed using a production-function methodology. This made use of publicly available data from EU sources and has the advantage of allowing for a consistent and objective evaluation of VoLL for each MS within the EU. The approach assumes that electricity is an important input into the production and consumption of goods and services for consumers, such that production or leisure enjoyment is reduced when there is a supply disruption. This allows for the impact on different sectors of the economy to be measured by using data on consumption, gross value added (GVA) and wage rates.

A number of assumptions are used within the production-function methodology. In order to refine our assumptions, we conducted primary research consisting of two web-based surveys – one for domestic consumers and one for non-domestic consumers. This also allowed us to meet some additional objectives of the research, including consideration of the impact of the duration of an interruption and of the provision of notice on VoLL. By gathering responses from 892 consumers in total, covering almost every MS in Europe[1], we have been able to refine our analysis in a number of areas.

Findings – domestic consumers

Our analysis yields VoLL estimates for domestic consumers which range between €1.50/kWh for Bulgaria and €22.94/kWh for the Netherlands. This range is broadly in line with findings from previous VoLL studies. As expected, we find that domestic consumers in Northern EU MS with higher incomes generally have higher VoLL. This is partly due the fact that consumers in Northern EU MS report a higher dependence on electricity for their leisure time – a relationship that has been studied for the first time as part of our primary research.

We observe that the reported willingness-to-accept (WTA) a financial amount in response to a hypothetical supply interruption increases with the duration of the interruption, but that the marginal willingness to accept (per hour) decreases.

By assessing the value that consumers place on the provision of one-day of notice ahead of a supply interruption, we have been able to estimate the Value of Lack of Adequacy (VoLA)[2]. When faced with a subsequent two-hour interruption, we find that one-day of notice leads to a reduction from VoLL to VoLA by just less than 50%. We also find evidence that the value of notice and the duration of a subsequent supply interruption are interlinked. Notice is relatively more beneficial when interruptions are of shorter duration. For example, for a two-day interruption, the reduction from VoLL to VoLA is less than 25%.

Findings – non-domestic consumers[3]

For non-domestic consumers, we find that reported dependence on electricity for productive output is greater than for domestic consumers. We also find that VoLL estimates vary depending on the sector. We identify a median value of less than €1/kWh for a number of industries but a median value of €17.76/kWh for the Construction industry, for example. Our results are generally in line with the findings of previous studies of VoLL.

We observe that some industries, such as the Construction industry, contain significant outliers of up to €113.00/kWh. We note that in many cases where outliers are present, they have also been identified in the results of previous studies. We present three hypotheses to explain these findings:

1. As VoLL is normalised using units of consumption, an industry with high GVA produced using small amounts of electricity may display VoLL estimates which appear high.

[1] Malta was the only MS from which no consumers provided a response to either of our surveys.

[2] I.e. the equivalent of the VoLL but when notice is provided one day ahead of the supply interruption.

[3] We refer to 'non-domestic' consumers throughout this report. In general, the term refers to any electricity consumer who is using electricity for purposes other than home use. More specifically, the term covers industrial and commercial consumers of all sizes.

2. A high VoLL estimate may not reflect the fact that electricity is a less critical input for the sector in question.
3. Inconsistencies or inaccuracies in the sectoral definitions or the data itself may lead to anomalies.

In relation to the impact of duration and notice, we observe similar trends as for domestic consumers. We note two interesting differences. Firstly, while WTA of non-domestic consumers increases with duration of the interruption, the WTA for a short interruption (20 minutes) is much closer to that for a longer interruption. This suggests that even short interruptions can result in significant detriment to production processes, and that consumers have incorporated damage or 'hassle' which may result from short term interruptions. Secondly, the benefit of notice is lower for non-domestic consumers, and particularly industrial consumers, than it is for domestic consumers.

Time-specific analysis

We have made use of EU consumption data to explore the relationship between the season of the year, day of the week and time of day and the dependence of domestic consumers on electricity (making use of the ratio between time-specific consumption and average consumption to define a demand factor). Seasonality of dependence is related to geographic location. Consumers in Northern MS have greater levels of dependence on electricity in winter while Southern MS consumers demonstrate a flatter seasonal profile with less pronounced winter and summer peaks.

An important limitation of our time-specific analysis is that time-specific consumption data for EU MS is only provided at the aggregate level. To test time-specific dependence across different consumer sectors, we make use of more disaggregated profile data available for the UK. This helps to validate our findings for seasonal time dependence, and to a lesser extent supports our findings for time dependence in relation to the time of day. However, it contradicts our EU-wide analysis of time-dependence relating to the day of the week.

Applications

We consider that a set of VoLL estimates for all EU MS developed using a common methodology could benefit policy makers, regulators and electricity market participants in a number of areas.

Given that our analysis represents a first in several areas, we consider that our findings in some areas (such as outcomes from our primary research, our time-varying analysis and consideration of VoLL for disaggregated Services sector) would benefit from verification through further research.

1. Introduction and Context

1.1. Requirements of this study

CEPA was commissioned by ACER to provide a study on the estimation of the VoLL of electricity supply in Europe. The requirements are broken down into two main tasks:

- **Task A**: Review and assess the concept of VoLL in electricity supply, in particular, its economic aspects, by conducting a review of the relevant academic literature, analysing and identifying methodologies used to derive VoLL, determining the relevant consumer types and assigning these consumer types into groups to which a similar VoLL can be attributed; and
- **Task B**: Provision of numerical estimates of VoLL for each consumer type/group for each European Member State (MS), considering the specific context of each individual MS, as well as different regulatory applications, if applicable.

This is our draft final report covering both Tasks A and B. In this study, we have applied our methodology to develop VoLL estimates across the EU and set out our findings. We also explore some of the challenges and limitations of our study. Based on this, we suggest areas for further consideration.

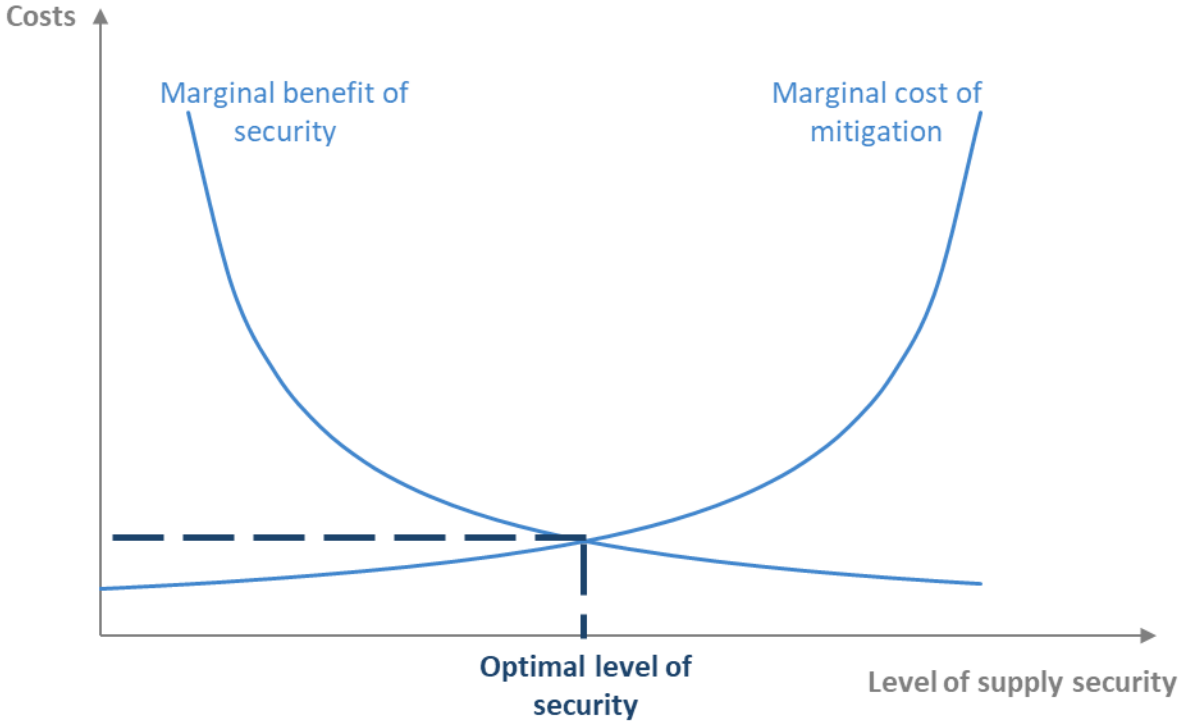
Our report is structured as follows:

- In the remainder of this section we introduce the concept of VoLL.
- In Section 2, we summarise findings from our review of the literature.
- In Section 3, we discuss practical applications of VoLL which may use the results of this study.
- In Section 4, we summarise our methodology, including the production-function method and our supporting primary research.
- Section 5 presents our segmentation of consumers for the purposes of analysis.
- Section 6 presents our findings; and
- Section 7 sets out our conclusions, including observations regarding use of our findings and proposals for further research.

1.2. The concept of VoLL

In modern societies, the vast majority of economically productive activity depends, at least to some extent, on electricity. While self-generation may be becoming more prevalent in some countries, electricity provided from the national electricity grids continue to form the bulk of electricity supply. Though electricity is provided with a high degree of reliability across Europe, with only infrequent and limited disruptions, it is clear that such disruptions can result in very high costs to society where they do arise. On the other hand, maintaining a high level of security of supply is costly, and no system can ever be 100% secure. The economically efficient level of security of supply is where the marginal benefit of an additional unit of supply security is equal to the marginal cost of maintaining that level of supply of security (see Figure 1.1).

Figure 1.1: Theoretical optimal level of security of electricity supply



Source: CEPA

VoLL provides a means by which the marginal benefits of additional security of supply can be measured. It allows a value to be placed on greater reliability of electricity supply by measuring the loss of socio-economic activity resulting from a unit of electricity not provided by the grid. In combination with metrics designed to measure a potential or actual volume of electricity which is not supplied, such as energy unserved, it can be used to define the potential impact on an individual, a company or on the economy as a whole.

1.2.1. Relevant developments in the EU

VoLL is becoming an increasingly important concept within the liberalised electricity markets of Europe. In particular, three relatively recent developments have highlighted the need for an informed valuation of supply security across the EU. These are:

- liberalisation of electricity markets;
- increasing penetration of intermittent renewable generation; and
- more flexible use of the electricity networks.

Market liberalisation

The liberalisation of electricity markets across Europe allows for more efficient flows of electricity based on the electricity prices within each respective market. It also discourages centralised planning and intervention in electricity markets, instead relying on market-based mechanisms to drive short-term operational and long-term investment decisions through price signals. While this should improve the efficiency of electricity markets, it also presents a shift away from centrally defined reliability standards. Approaches such as exogenous definition of 'reasonable' levels of lost load (e.g. by politicians or regulators) or engineering security standards (e.g. N-1 standards) have meant that supply security has not always been driven by quantitative measurements of the economic impacts of a loss of electricity. Without a basis in economic theory, these standards did not represent a socially optimal outcome from an economic perspective. In contrast, security of supply standards based on VoLL can improve the economic outcomes for consumers across the EU.

Increasing penetration of renewable generation

The EU's Renewable Energy Directive (2009)[4] set individual MS targets[5] for the share of energy needs met by renewables as part of a strategy for meeting long term greenhouse gas emissions reduction objectives. The increasing penetration of renewable generation may increase security of supply in the long term by diversifying the energy mix and reducing dependence on imported and depletable energy inputs, but it may also create security of supply concerns due to the intermittent nature of renewable generation, resulting in scarcity situations when the wind is not blowing, or the sun is not shining. As articulated in the proposed revision of the Renewable Energy Directive (November 2016)[6], the Commission proposes to address these situations through scarcity pricing which may be designed to incorporate VoLL.

Flexibility

Finally, partly in response to the other two drivers, new technological trends are emerging, such as electricity storage and electricity prosumers[7]. These new types of electricity providers enable a more flexible operation of the electricity networks. While in the past, networks have been built for one-way flows from large, conventional generation to centres of demand, and were sized relative to the peak demand on the system, new trends for two-way flows from more distributed resources require electricity network owners to re-think how their systems are used. Network owners are also increasingly able to consider alternatives to network reinforcement in response to increasing demand. For example, some network owners are

[4] https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

[5] Note that a proposal for a revised Renewable Energy Directive was published in November 2016. This sets EU-level renewable targets.

[6] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29

[7] A consumer who is also a producer of electricity. For example, a household consumer with solar mounted solar photovoltaic cells.

exploring greater use of more interruptible, rather than fully firm, connection agreements. Consumers may be increasingly able to express their VoLL through such mechanisms, while network operators may need to incorporate VoLL into their investment and operational decisions.

Security of supply and VoLL

None of these developments may lead to supply security problems per se. Electricity market liberalisation allows for more socially optimal outcomes in terms of the valuation of supply security. In addition, while renewables may at times cause difficulties matching supply and demand, many MS are developing their market designs and energy policy to cope.

For example, some MS have introduced capacity mechanisms to ensure that non-intermittent, controllable generation remains available to cover supply shortfalls. Increasingly, policymakers and regulators are also re-designing market structures and regulatory frameworks to introduce appropriate short-term and long-term price signals for system flexibility, whether relating to the supply side, demand side or use of the electricity networks. More flexible use of the network can also contribute to socially optimal outcomes. Rather than incurring the costs required to size networks for peak demand which occurs once per year, alternative, more flexible options can be explored.

ENTSO-E (2015)[8] notes the impact that these developments are having in the context of transmission system planning and investment:

'The move to a more diverse power generation portfolio due to the rapid development of renewable energy sources (RES) and the liberalisation of the European electricity market has resulted in more and more interdependent power flows across Europe, with large and correlated variations. Therefore, transmission system design must look beyond traditional (often national) transmission system operator (TSO) boundaries and move towards regional and European solutions.'

As we explore further in Section 3 of this report, measurement of VoLL can feed into all of these developments, allowing for a more effective and efficient transition to liberalised EU electricity markets. Furthermore, under the proposed Electricity Market Regulation within the 'Clean Energy for all Europeans' winter packages[9], ENTSO-E is required to develop a methodology for the calculation of VoLL. The Regulation states that:

"ENTSO shall submit to the Agency a draft methodology for calculating:

(a) the value of lost load;

(b) the "cost of new entry" for generation, or demand response; and

[8] https://www.entsoe.eu/Documents/SDC%20documents/TYNDP/ENTSO-E%20cost%20benefit%20analysis%20approved%20by%20the%20European%20Commission%20on%204%20February%202015.pdf

[9] https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v9.pdf

(c) the reliability standard expressed as "expected energy not served" and the "loss of load expectation"."

The difficulty for policymakers is that VoLL is not reflected in current market-based mechanisms (e.g. in market prices). Security of supply is not traded on a market place, and therefore, its value cannot be established directly[10]. As a result, the balance between costs and benefits of security of supply (e.g. using VoLL) must be estimated using alternative methods. We explore some of the most common methods in Section 2 of this report.

1.2.2. VoLL and Willingness to Pay/Accept

In addition to VoLL, there are other commonly used metrics which are used to evaluate the value that consumers place on an uninterrupted supply of electricity. As we discuss in our literature review, a number of studies use willingness-to-pay (WTP) or willingness-to-accept (WTA) for such purposes. It is important to be clear on the difference between WTP/WTA and VoLL. WTP/WTA measures the monetary value that consumers are prepared to pay/accept to avoid/experience a security of supply event (i.e. an outage) and is usually 'normalised'[11] using a unit of time – e.g. WTA/WTP is commonly measured in Euros per hour – reflecting the fact that the consumer is usually being asked to value their use of electricity over a certain time period.

VoLL on the other hand is normalised using a unit of energy – e.g. it is commonly measured in Euros per kWh/MWh of electricity. The difference between the two is important and can lead to findings which may at first appear counter-intuitive. We may generally expect that higher consumption is a reflection of greater 'dependency' on electricity. This effect will often lead to a higher WTP/WTA for consumers with higher consumption. However, this will not necessarily result in higher VoLL for that same consumer/event.

Because VoLL is normalised using a unit of energy, high levels of consumption (all else equal) have a downwards effect on VoLL. In practice, the effects of higher levels of consumption may therefore be expected to have two opposing impacts on VoLL. On the one hand, higher consumption may reflect a higher level of dependency on electricity, placing upwards pressure on VoLL. On the other, the normalisation of VoLL using units of energy will place downwards pressure on VoLL. The overall relationship between VoLL and consumption will result from the comparative strength of these two effects.

[10] Note that this may start to change in some economies as a result of new developments in metering and greater drives for flexibility. These developments may allow consumers to express a value that they place on electricity supply and allow them to benefit from savings on their energy bill through voluntary disconnections.

[11] Normalisation is used to ensure that findings from different studies and in different contexts are comparable to some extent. Rather than stating WTA/WTP for the acceptance/avoidance of a security of supply event overall, normalisation allows WTA/WTP to be measured in common units (usually using units of time). VoLL on the other hand is normalised using units of electricity consumption.

At least in theory WTP/WTA for an individual consumer can be converted into VoLL relatively easily. One must simply divide the WTP/WTA value by the amount of electricity consumed in the relevant period of time (e.g. consumption per hour). However, in practice, this can be more difficult. For example, granular consumption data is limited at a disaggregated level, and is not available at the level of an individual consumer[12]. In addition, discrepancies between WTP and WTA (which we explore further in our literature review) can result in significant differences in VoLL depending upon which metric is used to calculate it. This prevents many practitioners from converting WTP/WTA findings into VoLL, particularly when considering the relationship between VoLL and time of consumption throughout the day/year (time-varying VoLL) given the dependency on granular consumption data. Where they do convert estimates, they often apply simplifications, for example using day/night comparators of VoLL rather than developing hourly estimates.

[12] This may start to change with the emergence of smart meters and data analytics.

2. LITERATURE REVIEW

Our literature review covered a range of relevant studies and reports. Our intention was to cover VoLL estimates in different countries, focusing on the context of the EU and using various methodological approaches for estimating VoLL. We also considered a range of rationales for deriving VoLL estimates. The list of reviewed studies is provided in ANNEX A.

We set out our key findings from the literature review in the remainder of this section.

2.1. Methodological approaches for calculation of VoLL

Broadly speaking, methodologies for calculation of VoLL can be separated into stated preference approaches and revealed preference approaches. Put simply, stated preference methods measure what individuals *say,* whereas revealed preference approaches measure what they actually *do*.

To some extent this means that revealed preference methods can be argued to be a more accurate reflection of actual consumer activity. However, they are also dependent on availability of data which can either allow for a direct measurement of VoLL or can allow for its indirect inference. The situational context to allow for direct revelation of VoLL is very infrequent, particularly given the high levels of supply security in the EU. Indirect methods may be less dependent on context. However, these methods require several simplifying assumptions. These assumptions may reduce accuracy, and potentially limit the extent to which the numerous costs which consumers may face in the event of a disruption can be captured.

Stated preference methods rely on surveying of consumers to elicit stated valuations relating to varying levels of supply security. A number of stated preference approaches are used, including WTP, WTA and direct worth[13].

A summary of the advantages and disadvantages of the methodological approaches identified in the literature is presented below. We provide further detail on each of these approaches in ANNEX A.

[13] WTP asks consumers what they are willing to pay for an additional level of supply security and WTA asks consumers what they are willing to accept to experience a lower level of supply security. Direct worth surveys encourage consumers to think about the actual costs that they would incur as a result of a supply disruption. We explain each of these approaches in more detail in ANNEX A.

Table 2.1: Advantages and disadvantages of methodological approaches for calculating VoLL

Methodology	Advantages	Disadvantages
Stated preference	• Bespoke scenarios can be identified to consider particular applications (e.g. duration, notice periods, etc.). • Can include broader economic considerations (e.g. damages to goods). • Can be utilised with almost any consumer type. • Not dependent on consumers having experienced an actual supply interruption. They are able to respond based on consideration of hypothetical events.	• Subjective and thus dependent on culture, context and state of mind. • Large discrepancy between VoLL estimates based on WTP and WTA. No consistently applied approach for deciding which to use. • Dependence of results on surveying approach (e.g. interview/questionnaire, wording of questions, form of response). • Practitioner may have undue influence on results through design of survey. • High cost and time requirement. Large samples of consumers need to be recruited.
Case studies	• Study of real-life situations. No need for hypothetical and subjective scenarios.	• Limited applications (particularly where interruptions are relatively infrequent (e.g. in Europe)).
Market behaviour analysis	• Study of real-life situations. No need for hypothetical and subjective scenarios. • Broader reference cases than under case studies, particularly for non-domestic consumers. • May become more applicable as technology and market design increases the ability of consumers to express values.	• Difficult to incorporate less direct costs, particularly for households. • Difficult to establish true socio-economic costs based on measures in place for low frequency events. • Difficult to apply in countries with well-developed and relatively reliable electricity systems.
Production-function	• Provides consistent means for measuring VoLL for the whole economy. • Allows for consistent estimates across borders, accounting for specificities but removing subjectivity of interpretation. • Uses macroeconomic data hence is relatively low-cost and with a low time burden. • Easily replicable at regular intervals once data sources have been established.	• Dependent on data availability and quality for analysis. • A number of assumptions are needed to feed into calculations. • Can be difficult to incorporate bespoke requirements (e.g. impact of duration and notification). • Does not incorporate costs to the consumer which are not related to production, leisure time e.g. 'annoyance' costs, damaged goods, etc. • Can provide high estimates for certain sectors that have small consumption levels[14].

Source: CEPA analysis

[14] However, it should not necessarily be inferred that these estimates are not a 'true' reflection of VoLL. We explore this further when discussing our findings.

2.2. Consumer segmentation

In order to estimate VoLL, electricity consumers are segmented into groups for which VoLL estimates can then be derived. In reality, each consumer is likely to have a different VoLL depending on a number of factors, such as their consumption level, use of electricity and outside options such as on-site generation. However, for practical reasons, VoLL studies segment relatively homogeneous types of consumers into different consumer groups. For example, domestic consumers are considered as one homogenous group, while industrial consumers may be segmented into sub-groups depending on the nature of their economic activity. In addition to identifying different VoLL estimates for each of these consumer segments, the segmentation methodology applied can differ for theoretical and practical reasons, such as data availability or the ease with which surveying can be carried out on each consumer segment.

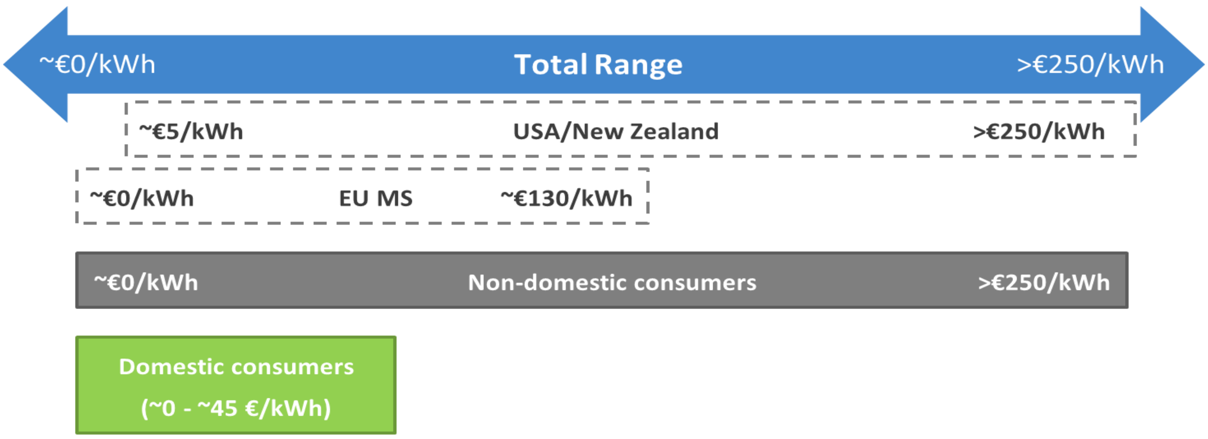
Our review of the literature indicates that there is no commonly agreed segmentation of consumers nor a consistent methodological approach for determining consumer groups. Rather, each study defines its segmentation of the market based on a number of variables that include the context, intended use and practicalities of analysis, such as availability of data.

In ANNEX A we summarise the market segmentation included within a range of studies which estimated VoLL for non-domestic consumers. We also specify the methodological approach used.

2.3. VoLL estimates found in the literature

We find that VoLL estimates are highly dependent on a number of factors, including geography, context, consumer type and methodological approach. Figure 2.1 summarises the range of VoLL estimates reported for different consumer groups in the studies reviewed[15].

Figure 2.1: International range of VoLL estimates



Source: CEPA analysis

[15] In addition to studies which estimate VoLL directly, our analysis of VoLL estimates includes consideration of meta-studies such as Schroder and Kuckshinrichs (2015). Values are in 2013 euros.

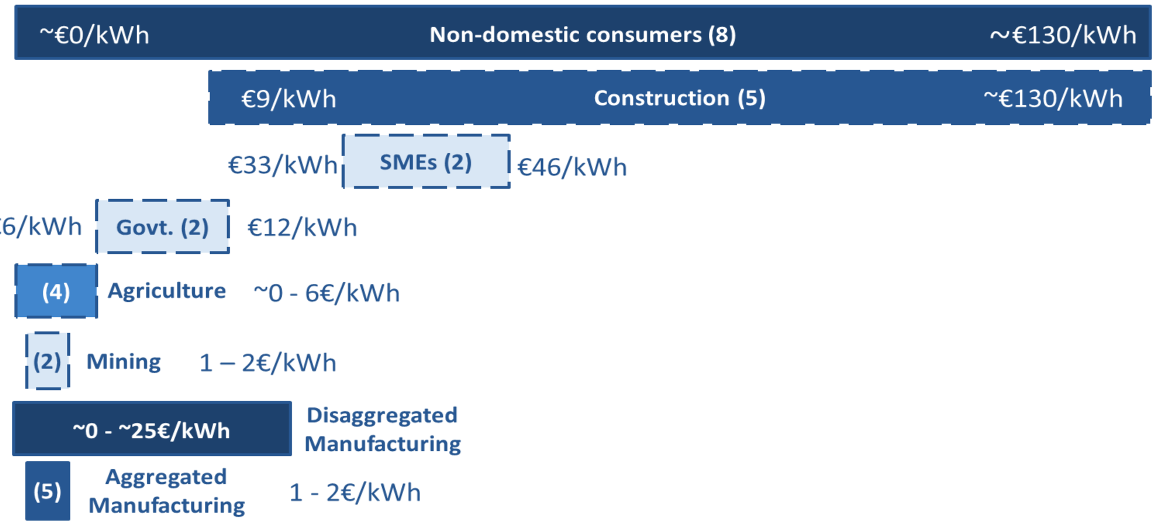
Overall, the reported VoLL estimates range from close to €0/kWh to over €250/kWh. While still wide, the range reported for European MS only is smaller reaching approximately €130/kWh. In general, we find that consumers in the Services sectors have higher estimated VoLL than Industrial or domestic consumers.

VoLL estimates for domestic consumers through the use of stated preference approaches are generally in the region of €10/kWh. WTA methods almost always elicit higher VoLL estimates than WTP. Macroeconomic approaches, such as the production-function method, usually yield higher estimates for domestic consumers than stated preference approaches, with VoLL estimates in the range of less than €1/kWh to €25/kWh. Interestingly, the relationship between the methodology employed and VoLL estimates for non-domestic consumers is often the opposite of what is observed for domestic consumers. Where they are used, stated preference methodologies can elicit higher VoLL for non-domestic consumers than macroeconomic VoLL estimates[16].

While Figure 2.1 allows for a high-level assessment of the ranges of VoLL for different consumer types, the range of VoLL estimates for non-domestic consumers suggests significant heterogeneity of consumers within this group. We explore those studies carried out in EU MS in which further disaggregation has been applied for non-domestic consumers in Figure 2.2. We also show VoLL estimates where the sub-group of Manufacturing consumers has been further disaggregated in Figure 2.3. In both figures, the number of studies in which this consumer type has been considered is shown in brackets and is further indicated by the shading of the relevant bar (a darker shade indicates that the sub-group has been included in a greater number of studies).

[16] This may be partly due to strategic responses. Non-domestic consumers may be more inclined to consider that their responses can influence findings and, in turn, policy outcomes. They may expect statements of high VoLL levels to be in their interests – for example in relation to rules surrounding compensation or in terms of implications for network investment and improvements to security of supply.

Figure 2.2: VoLL estimates of disaggregated non-domestic consumers for EU MS studies only



Source: CEPA analysis

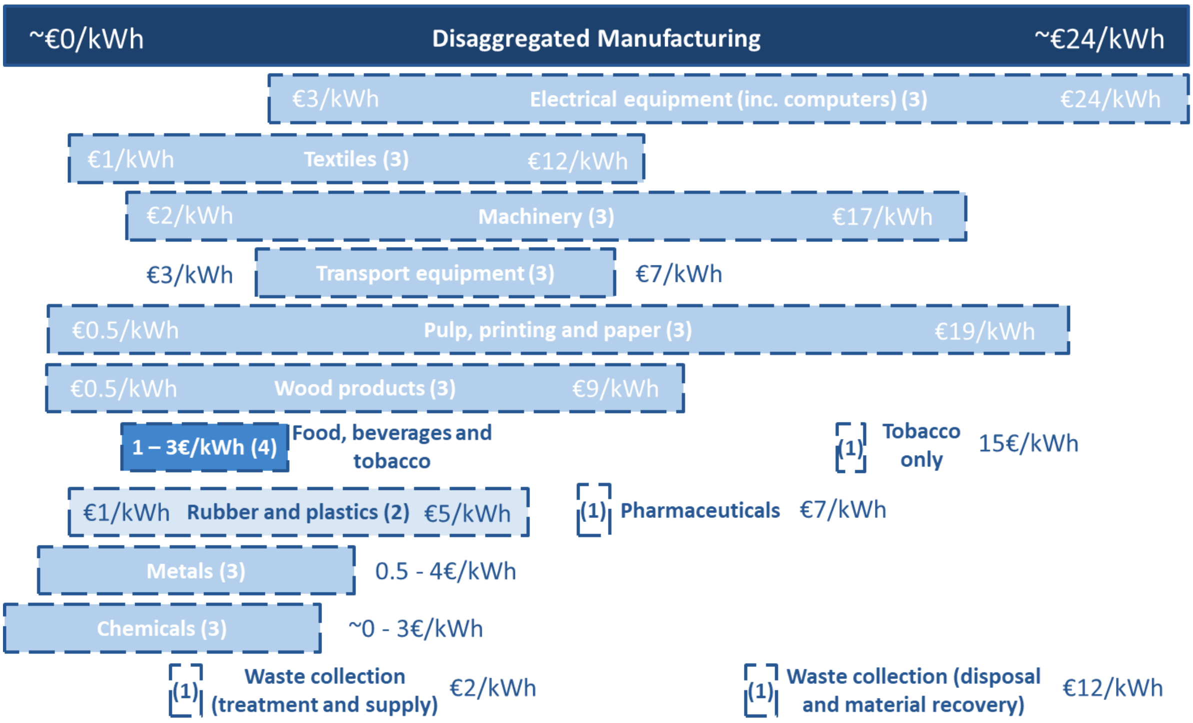
The Construction industry tends to be an outlier among non-domestic consumers, with VoLL estimates often above €100/kWh. One explanation for this relates to the application of the production-function method. Because the determination of VoLL takes electricity consumption as the denominator for normalisation of results, high VoLL estimates can be derived for industries with relatively low levels of electricity consumption (such as the construction industry; London Economics (2013)). It is important to consider the reasons for this when interpreting results. We include discussion of this effect when presenting our findings in Section 6.2.

Figure 2.2 may underestimate the frequency with which small- and medium-sized enterprises (SMEs) are considered as a sub-group of non-domestic consumers as they are often considered separately from non-domestic altogether, even utilising a different methodological approach (e.g. London Economics (2013)). Where SMEs are considered as a sub-group of non-domestic consumers, they generally have a higher VoLL than that found for other non-domestic consumers, save for the construction industry.

For the sake of simplicity, we include government/public administration within the Services element of the non-domestic definition. We find that government/public administration has a higher average VoLL estimate than the non-domestic consumer sub-sectors in the two studies where they are considered as a specific sub-group.

In VoLL studies where manufacturing is considered as a homogeneous group, we find VoLL estimates that are broadly in line with the agricultural and mining sectors. However, when disaggregated, it becomes apparent that this may hide a more heterogeneous sub-group of consumers. We explore the manufacturing sub-group in more detail in Figure 2.3.

Figure 2.3: VoLL estimates of sub-groups of manufacturing consumers



Source: CEPA analysis

In our analysis of the Manufacturing consumer group, we find that several consumer types continue to have a relatively wide range of VoLL estimates even when further disaggregated. This suggests that a level of heterogeneity within these disaggregated consumer groups remains. Given that these studies are often conducted at a national level, the differences in VoLL estimates between studies may also suggest that the VoLL of these consumer types may vary depending on the specific national context (e.g. the economic and contextual conditions for non-domestic consumers) of that particular country. Alternatively, it may result from discrepancies between countries in terms of how sectors are defined or how output (e.g. GVA) and consumption data is collected and processed.

2.4. Consideration of timing, duration and notification of outages

A number of studies consider the impacts of the time of day or year and the duration of the supply disruption on consumer valuation. While some of these studies approximate the impact of timing and duration on VoLL, the majority consider WTP/WTA, and refrain from converting estimates to VoLL given the challenges with consumption data discussed previously. This is particularly the case where survey-based approaches have been used. We have not found evidence that the quantitative impact of notification on consumer valuations has been considered to any great extent.

Timing

Some non-domestic consumers may be able to shift productive activity relatively easily, particularly if given notice, and hence may have a relatively smooth VoLL profile over the course of a day or a year. However, for domestic consumers in particular, we expect that VoLL is more time dependent. For example, in the middle of a summer day, domestic consumers may be able to spend time on leisure activities which are less dependent on electricity. In contrast, on a dark, cold night they may value electricity provision more highly. Therefore, WTP/WTA will likely be higher on the winter night.

However, given the normalisation of VoLL using units of energy, there will also be a relationship working in the opposite direction. On a summer day, consumption will most likely be lower than on the winter evening, which will have the effect of increasing VoLL (all else equal). The overall impact on VoLL will depend on the relative strength of these two opposing effects.

We also expect this relationship to be quite different for consumers depending upon their location. Domestic consumers in northern Europe may be more dependent on electricity (and have higher consumption) on a winter evening when it is needed for lighting, and potentially heating. Conversely, it may be air conditioning in summer that drives maximum WTP/WTA in Southern EU MS.

Some studies consider the impact of timing (season, day of the week and time of day) on the VoLL of consumers. Shivakumar et al. (2017) estimate the impact of time of day and year on VoLL for domestic consumers by incorporating hourly consumption data into their production-function methodology. They find some general trends; for example, that VoLL is the lowest at night – between the hours of 23:00 and 06:00, and that VoLL is greatest between 17:00 and 21:00.

Furthermore, they find the relationship between VoLL and the time of day and year to be dependent on the country in question. Households in northern European MS have the highest VoLL in winter months. For example, the highest VoLL is found in Denmark and the Netherlands between 17:00 and 19:00 from November to February. In contrast, VoLL is the highest in the summer months in southern Europe. In particular, Italian domestic consumers are found to have the highest VoLL between 10:00 and 16:00 from June to August. Shivakumar et al. (2017) also find that domestic consumers in central European MS generally show less seasonal variation than do those in northern or southern Europe.

Leahy and Tol (2010) use a similar approach for the case of the Republic of Ireland and Northern Ireland with findings for domestic consumers consistent with those of Shivakumar et al.

Leahy and Tol (2010) also provide one of the few examples of consideration of timing of outage on non-domestic consumers. They identify the highest VoLL for these consumers between the hours of 8:00 and 18:00 on weekdays. However, as would be expected, VoLL for non-domestic, and particularly industry consumers, is significantly flatter over the time of day and year. While there is some, though limited, differentiation between night and day and summer and winter for the VoLL of Service sector consumers, the VoLL of Industry consumers is almost constant over time.

Duration

The duration of a supply disruption is clearly an important driver of VoLL. Generally, we would expect VoLL to increase with the duration of disruption. However, the relationship between duration of interruption and VoLL is unlikely to be linear or uniform between consumers.

Intuitively, we may expect the rate of increase of VoLL (expressed as the marginal VoLL) to decrease as the length of disruption increases. This is because as duration increases, the relevance of the initial 'annoyance factor' decreases and consumers are better able to engage in other activities which are less dependent on electricity (the 'adaptation effect'). For example, even a very short disruption (of the order of seconds) could result in a need to re-boot machinery or computers and to invest time in processes to get back to full efficiency. However, there may be some consumers and some industries where interruptions of short durations are more manageable, while longer durations result in high levels of disruption. For instance, industries which are dependent on refrigeration may be able to cope with a short outage without much reduction in output but may start to suffer from expiry of stock after a certain period of time.

The importance of duration is evident within some of the most common indices which are used for measuring supply continuity and security in regulatory applications. The System Average Interruption Duration Index and the Customer Average Interruption Duration Index[17] are commonly applied in national regulations and performance-based incentives for network security standards, for example.

The impact of outage duration on VoLL has been considered in several studies. However, the way in which this impact is measured is not consistent. For example, questions regarding duration of outage have been included within a number of WTP and WTA surveys, but the lengths of duration considered differ from one study to the next. As mentioned previously, these surveys are also rarely normalised using consumption to derive VoLL which can make it difficult to compare the results.

Overall, the majority of studies found that marginal WTP/WTA decreases with duration, in line with the intuitive rationale expressed above. Studies which find this relationship include Reichl et al. (2012), Bliem (2009), Bertazzi, Fumagalli and Schiavo (2005) and London Economics (2013). However, given the nature of the methodological approach taken, this evidence is generally limited to Domestic and Service sector consumers.

[17] Both of these indices measure the average duration of interruption.

In their study of WTP to reduce outages for domestic consumers, Carlsson and Martinsson (2007) provide the only example that we have found in the literature of increasing marginal WTP with increasing outage duration.

We summarise findings from the literature in the table below:

Table 2.2: Summary of literature which considers duration of interruptions

Study	Customers considered	Durations considered	Increasing/decreasing marginal WTP/WTA/VoLL
Bertazzi, Fumagalli and Schiavo (2005)	Domestic, Services	3 minutes, 1 hour, 2 hours, 4 hours, 8 hours	Decreasing (with exception of interruptions of 3 minutes)
Bliem (2009)	Domestic, Services	3 minutes, 30 minutes, 4 hours, 10 hours	Decreasing
Carlsson and Martinsson (2007)	Domestic	4 hours, 8 hours, 24 hours	Increasing
London Economics (2013)	Domestic, Services	20 minutes, 1 hour, 4 hours	Decreasing
Reichl et al (2012)	Average across whole economy	1 hour, 4 hours, 12 hours, 24 hours, 48 hours	Decreasing

Source: CEPA analysis

Provision of notice

In some instances, electricity sector participants (e.g. network companies or system operators) may be able to provide notice ahead of a supply disruption. For example, an outage may be planned ahead of time in order to conduct necessary maintenance on a power line or substation. Consumers will differ in the extent to which the provision of notice impacts on their valuation of the supply disruption. Some consumers may be better able to plan ahead, for example by charging electronic devices, preparing back-up equipment or rescheduling activities. This may enable them to use time productively without electricity given sufficient notice. Others may be less able to shift productive activities or utilise outside options. Their valuation may remain almost the same regardless of whether notice is provided.

While some studies have indicated that provision of notice was included as an attribute[18] or have included qualitative consideration of the impact of the provision of notice on VoLL (e.g. Ajodhia (2005)), we find only two studies which included consideration of the quantitative impact of the provision of notice. Reichl et al. (2012) use data obtained from a WTP study but find no statistically significant relationship between the provision of advance notice and VoLL for domestic consumers[19]. On the other hand, Carlsson et al. (2009) find that when three working days of notice is provided ahead of a disruption, WTP decreases and the proportion of individuals stating a WTP of zero increases – i.e. consumers place a lower value on avoiding the disruption in the case that notice is provided.

[18] For example, Latwon, Eto, Katz and Sullivan (2003) and Hoch and James (2011).
[19] The number of hours of warning ahead of interruption is not specified in the report.

3. USES OF VOLL IN EU ENERGY POLICY

In this section, we explore actual and potential regulatory applications of VoLL and set out our thoughts on where estimates derived based on a common EU-wide methodology may be most applicable.

3.1. Types of regulatory application

There is a broad range of intended or actual applications of VoLL found in the literature. These can be grouped into four themes:

- policy and infrastructure analysis and evaluation;
- regulatory incentives and consumer compensation;
- wholesale market design and price signals; and
- direct procurement of security of supply.

We briefly discuss each of these applications below.

Policy and infrastructure analysis and evaluation

We have found several areas in which governments, national regulatory authorities (NRAs), TSOs and independent researchers use VoLL to aid the evaluation of policies or initiatives.

For example, countries with a relatively high frequency of supply disruption often seek to measure VoLL to evaluate the economic impacts of existing levels of supply security, and thus, the economic value placed on increasing it. For example, Bouri and El Assad (2016) attempt to measure the economic impact of supply disruptions in Lebanon.

VoLL can also be used as a means to evaluate the benefits of cross-border infrastructure investments. Under EU Regulation 347/2013[20], ENTSO-E is required to establish a '*…methodology, including on network and market modelling, for a harmonised energy system-wide cost-benefit analysis at Union-wide level for projects of common interest.*'

ENTSO-E suggests that '*…transmission system design must look beyond traditional (often national) TSO boundaries, and move towards regional and European solutions.'*

In relation to approaches for monetisation of costs and benefits of options, ENTSO-E considers estimating the costs associated with low levels of reliability using expected energy not supplied multiplied by VoLL. However, it identifies the large variation in VoLL estimates which are currently used between regions as a limiting factor in applying such an approach. This leads to a suggestion that, even with *national* VoLL estimates as recommended by the Council of European Energy Regulators (CEER), the high levels of variability and complexity of VoLL mean that its use '*…will only provide indicative results which cannot be monetised on a Union-wide basis*'. By applying a consistent methodology for all EU MS, our study aims to bridge this

[20] http://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex%3A32013R0347

gap. The methodology is also designed so that it can be built on and updated by future research. This should allow for cross-border infrastructure cost-benefit analyses (CBAs) to be informed using pan-European VoLL estimates.

At a more general level, governments and regulators are increasingly seeking to establish or make use of VoLL estimates to evaluate the benefits of new and existing policies. This may be applied both to establish whether to introduce new policies, and to evaluate the impacts of policies related to security of supply post-implementation.

Regulatory incentives and compensation

One of the most common uses of VoLL within the EU is for the design of performance-based incentives for network companies to encourage a desired or (improved) level of continuity of supply. Examples include, but may not be limited to, the UK, Germany, Italy, the Netherlands and Norway. Well-designed incentives for supply continuity should also feed into network operator decision-making in relation to planning, infrastructure investment, operation and maintenance and contingency planning.

Wholesale market design and price signals

In addition to network regulation, some NRAs have incorporated VoLL into their wholesale market design. The study of VoLL conducted by London Economics (2013) was commissioned for the purpose of providing an estimate that could be incorporated into the 'cash-out', or imbalance, pricing arrangements in Great Britain. These cash-out arrangements are designed to incentivise market participants to balance their supply and demand positions. Ofgem subsequently included this estimate to price 'demand control actions' into the wholesale market under its electricity balancing significant code review[21]. A cost for disconnections based on VoLL was introduced into the 'cash-out' price, which applies to supplier imbalance volumes. In addition, Ofgem introduced a reserve-scarcity price function to price reserves. This reserve-scarcity price is based on the prevailing scarcity on the system using VoLL and the loss of load probability (LOLP).

At a pan-European level, VoLL is also intended to play a role in regulatory market design. Under the Capacity Allocation and Congestion Management guideline, Nominated Electricity Market Operators are supposed to 'take into account an estimation of VoLL' in setting harmonised maximum and minimum clearing prices. These clearing prices are to be applied in bidding zones which participate in day-ahead and intraday coupling mechanisms.

Direct procurement of security of supply

Finally, VoLL may feed into the direct procurement of capacity or system services designed to enhance system security. For example, VoLL may be used in the design of capacity markets to

[21] https://www.ofgem.gov.uk/sites/default/files/docs/2014/05/electricity_balancing_significant_code_review_-_final_policy_decision.pdf

monetise the value of additional supply security, and hence, identify the volume of capacity that should be contracted and the corresponding price.

System operators also procure a number of services in order to enhance supply security, or in the case of black start services, to restore the system in the event that a blackout occurs. VoLL could support the derivation of an economically optimal volume and price for these services.

3.2. Applications of VoLL in the EU

The table below presents a range of regulatory applications of VoLL and our view on whether they require use of VoLL determined using a consistent EU-wide, regional or national estimation methodology[22]. We provide a more detailed description of each of these applications and further rationale for our position in ANNEX B.

[22] For clarity, by EU-wide VoLL estimates, we do not mean a single VoLL figure that is applied across the EU. Rather, we mean a set of VoLL estimates that are defined for the whole of the EU using a common methodology (e.g. the estimates derived under this study). The same logic applies to our definition of 'regional' VoLL estimates.

Table 3.1: Nature of VoLL methodology proposed for different regulatory applications

Nature of VoLL methodology	Regulatory application
EU-wide	EU network planning
	EU-wide cost-benefit analyses
	System adequacy assessments
EU-wide/Regional	Setting harmonised maximum and minimum clearing prices
Regional	Wholesale market scarcity price signals
	Driving optimal procurement levels for balancing and back-up services (e.g. black start)
Regional/National	Design of MS-level capacity markets
National **(but may be preferable to use Regional/EU-wide estimates in practice)**	National network planning
	National cost benefit analyses
National	Defining interruptions incentives and compensation to customers in the event of disconnection
	Distribution network planning and considering operational alternatives (e.g. demand side response)
	Informing the order of disconnection in the event of a supply disruption

Source: CEPA Analysis

4. METHODOLOGICAL APPROACH

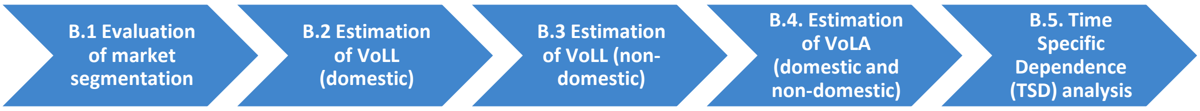
In this section, we summarise the approach that we have employed to develop estimates of VoLL across the EU for domestic and for non-domestic consumers. First, we explain our rationale for using the production-function approach and how we applied this to calculate VoLL. We follow this with a summary of the approach taken for our primary research which was used to complement the primary approach. A more detailed description of our methodology, assumptions and data sources can be found in ANNEX C.

4.1. Summary of our production-function methodology

We have applied a production-function approach to develop estimates of VoLL for both domestic and non-domestic consumers. This approach requires the use of a number of assumptions.

We summarise the methodology that we have followed in the remainder of this section. The five key steps, defined as sub-tasks of Task B, are outlined in Figure 4.1 below:

Figure 4.1: Steps used to estimate VoLL using the production-function approach.



Each of the five steps are outlined below:

Step B.1: Evaluation of market segmentation

The first step under our methodology was to develop our 'market segmentation' approach. This refers to the way in which we separate consumers into a discrete number of groups in order to develop common VoLL estimates. While we decided to consider domestic consumers as a single homogeneous group (consistent with the literature), we wanted to differentiate groups of non-domestic consumers given their inherent heterogeneity.

Our segmentation was driven by two factors. Our literature review helped to inform common segmentation approaches against which we sought to align our analysis. In addition, our segmentation was driven by an appraisal of the available data. Non-domestic VoLL estimates require data on GVA and on consumption. Our market segmentation was therefore driven by the extent to which such data was available. We set out our market segmentation in Section 5.

Step B.2: Estimation of domestic VoLL

For domestic consumers, our methodology for calculation of VoLL consists of the steps set out in Figure 4.2. More detail on each of these steps can be found in ANNEX C.

Figure 4.2: Approach to calculating VoLL for domestic consumers

Step 1: Calculate the leisure value for households in each MS

- 1a: Estimate time spent on leisure activities by employed individuals.
- 1b: Calculate the value of leisure for employed individuals, assuming that individuals at the margin are indifferent between an additional hour of labour and an additional hour of leisure.
- 1c: Develop assumptions of the "substitutability factor": the proportion of leisure value that is reliant on the supply of electricity.
- 1d: Apply an assumption regarding the value of leisure time for non-employed individuals relative to employed individuals (the 'non-employed' factor). We also carried out sensitivity analysis to explore the impact of varying the assumption in relation to the non-employed valuation of leisure time.

Step 2: Calculate average household VoLL for each MS

- Use the formula: $VoLL_{MS} = \frac{LV_{MS}}{ELC_{MS}}$ where LV_{MS} is the household leisure value and ELC_{MS} is the annual household electricity consumption.

After defining an average VoLL, we can make use of the findings of our primary research in order to measure how this varies depending on the duration of an electricity interruption.

Step B.3: Estimation of non-domestic VoLL

We adopt a methodology for non-domestic consumers which is conceptually similar to the approach used for domestic consumers. However, for non-domestic consumers, we relate electricity use to the actual value of output (measured using GVA), rather than the value placed on leisure time. As for domestic consumers, we also assess the relationship between non-domestic VoLL and duration using results from our primary research.

Step B.4: Estimation of VoLA

A further objective of this study is to estimate the VoLA[23] - i.e. VoLL with one day of notice provided ahead of the interruption.

This assumes that given one day of notice, consumers would be better placed to avoid the reduction in value (whether of leisure time or GVA) that would otherwise result from the outage. Intuitively, households may be better able to schedule leisure activities which are less reliant on electricity, such as sporting activities. Alternatively, households may plan ahead, for example, by ensuring that electronic devices are suitably charged or by investing in outside options (e.g. battery-powered torches).

[23] ACER define this as the value placed on supply in the presence of one day of notice ahead of a supply disruption.

In order to conceptualise this within our methodology, we introduce a 'notice factor' into our analysis. This notice factor is similar to the substitutability factor in that it represents the extent to which consumers are dependent on electricity. However, while the substitutability factor represents dependence on electricity per se, the notice factor represents the extent to which the addition of one day of notice allows the impact of the electricity disruption to be reduced. Like the substitutability factor, it takes a value of between zero and one with a high value (close to one) implying that the benefit of notice is low, such that VoLA remains close to VoLL.

Unfortunately, there is a lack of available data on consumer response to a one-day notice in advance of an outage from which to draw a baseline assumption. Therefore, we used our primary research to explore this issue. We asked respondents a number of questions in relation to their WTA under scenarios with and without notice ahead of the disruption. This allowed us to draw conclusions regarding the notice factor and how it varies relative to the duration of outage that is subsequently experienced.

VoLA is then estimated by multiplying VoLL by the notice factor. We can also consider the relationship between VoLA and the duration of the interruption.

Step B.5: Time specific analysis

The domestic and non-domestic VoLL estimates calculated in Steps B.2 and B.3 provide an annual average of VoLL. However, the value of electricity to consumers over the year will vary depending on the extent of dependence on electricity (i.e. the time specific substitutability factor) and on their level of consumption.

Accurate calculation of VoLL at any point in time would require time-specific valuation of leisure and of consumption. However, we must apply adaptations to this approach for two reasons:

1. Hourly *consumption* data is available from ENTSO-E but is aggregated at the level of the whole economy[24] rather than for specific consumer sectors.
2. Knowledge of time-specific valuation of *leisure* over the course of the year is not feasible.

These limitations in the data prevent us from specifying a time-varying VoLL. We have therefore modified our approach. We make use of the 'demand factor' which provides a proxy for the time-varying value of electricity for any consumer. This demand factor is equivalent to the time-specific electricity consumption in each hour divided by the annual average electricity consumption.

We then assume that the level of dependence on electricity for value of leisure time is correlated with the level of consumption, i.e. that higher consumption implies greater

[24] Hourly load data for Malta was not available.

dependence. We can use this to define a Time Specific Dependence (TSD) on electricity by multiplying VoLL by the demand factor.

We note that TSD should not be interpreted as 'time-specific VoLL'. Unlike VoLL, TSD is not normalised using consumption. Instead, it uses the demand factor to provide a measure of a consumer's 'dependence' on electricity and therefore correlates with the level of consumption of domestic consumers at any point in time.

Using our TSD function, we estimate the effect of seasonality, day of the week and time of the day on the value that consumers place on electricity supply. In addition, we attempt to differentiate TSD by domestic and non-domestic consumption more accurately for the case of the UK by analysing load profiles constructed by ELEXON[25] These load profiles cover different categories of electricity consumers (domestic, non-domestic, and non-domestic maximum demand customers[26]) which we can map onto our consumption sectors.[27]

4.2. Supporting primary research

We selected the production-function methodology given the advantage that it allows us to employ a consistent approach across Europe, making use of readily available macroeconomic data. Our methodology was therefore not dependent on the use of primary research.

However, the production-function methodology requires several assumptions. While there is precedent in the literature for the assumptions used, we wanted to increase the robustness of our analysis by refining these assumptions using surveying of domestic and non-domestic electricity consumers. In addition, we considered that a number of the bespoke objectives of this research (evaluating the interaction between duration, provision of notice and timing of an interruption), would benefit from surveying of consumers.

While developing this research, we had to remain conscious of the scope, budget and time requirements for this project. In order to gather information from a range of consumers across Europe within these constraints, we utilised web-based surveying.

In this section, we summarise our primary research. We also elaborate on its limitations at the end of this section.

4.2.1. Purpose

We had three main objectives for the use of our primary research:

[25] ELEXON is the code administrator for the Balancing and Settlement Code and the settlement agent for the electricity market in Great Britain: https://www.elexon.co.uk/about/who-we-are/.
[26] This is defined as those customers who had a maximum demand of 100kW at the time of introduction of the settlement class system.
[27] More details can be found at https://www.elexon.co.uk/operations-settlement/profiling/.

1. **Refining baseline assumptions**: The production-function methodology incorporates assumptions, such as the substitutability factor. We used our primary research to test and refine the assumptions that have historically been used in the literature.
2. **Informing additional analysis**: We used our primary research to inform this analysis into the relationship between factors such as duration, the provision of notice and the time of an interruption on VoLL, e.g. through the development of a 'notice factor' to understand how VoLL varies when notice is provided.
3. **Understand differentiation of assumptions based on region or consumer characteristics**: By recruiting respondents from across Europe and by gathering data on basic characteristics such as employment status, we were able to consider whether VoLL, or the assumptions that feed into it vary depending on such conditions.

4.2.2. High-level summary of responses

We reserve an exploration of the findings from our primary research for Sections 6.1 and 6.2. However, we summarise some key features of the responses below.

- **Number of responses to domestic survey**: We received a total of 768 responses to our domestic survey with 490 respondents completing all of the survey questions.
- **Number of responses to non-domestic survey**: We received a total of 124 responses to our non-domestic survey with 77 respondents completing all of the survey questions.
- **Regional contribution of responses (domestic survey)**: There was a broad range of responses across the EU. All MS (with the exception of Malta) submitted at least one response. Six MS submitted at least 50 responses and 17 MS submitted at least 10 responses.
- **Regional contribution of responses (non-domestic survey)**: The spread of responses was also positive. Only six MS did not include any responses. 13 countries provided four or more responses.
- **Employment status of respondents to our domestic survey**: More than 85% of those who stated their employment status were employed and working full time. In combination, 32 respondents were non-employed (in education, unemployed, retired or disabled) and 22 respondents were working part-time.
- **Cross-sector responses (non-domestic survey):** We also witnessed a spread of responses across non-domestic sectors. The only non-domestic sub-sector that did not receive a response was Fishing. While most sectors had a least one response, many were limited to a small number. Eight of the 21 sectors included within our study provided at least five responses.

- **Size of non-domestic respondents:** There was some representation of SMEs in the non-domestic survey. 31 responses out of 123 stated that they were SMEs while 12 did not state whether they were SMEs or not. More than 50% of respondents to the non-domestic survey stated that they spent more than €1 million on their annual electricity bill.

4.2.3. Limitations

We have limited the use of our primary research to the refinement of key assumptions within our production-function analysis and to exploration of some key factors which may influence VoLL (e.g. duration and notice).

Nevertheless, despite playing a supporting role in our primary research, we acknowledge some important limitations in the table below.

Had we used our primary research to draw conclusions directly relating to VoLL, these limitations may have undermined the calculation of VoLL. However, we consider the impact of sample bias and strategic response to be relatively low in relation to our objectives. For example, we see no reason to believe that the substitutability factor of English-speaking, computer-literate consumers would be heavily biased in one particular direction.

Nonetheless, it is important to understand potential limitations of this analysis in drawing and using conclusions. While we consider the approaches used to be sufficiently robust for our purposes, we also propose that further research be targeted on refining and validating these findings where possible.

Table 4.1: Limitations of primary research

Limitation	Explanation	Impact on results
Web-based survey	Web-based surveying relies on respondents having access to the internet and observing communications used to encourage responses.	**Sample bias**: The demographic of respondents will not be representative of the general population, given the pre-condition for accessing the survey.
English only	Given the broad intended reach of the survey and the limitations on budget, it was not practical to translate the survey into multiple languages. English was selected as the chosen language, given that this was expected to have the broadest reach.	**Sample bias**: Responding to the survey required a sufficient level of English. This may have discouraged responses from some regions and may have biased our sample towards consumers with higher levels of education.
Promotion approach	The survey link was mainly promoted via CEPA, ACER and NRAs, as well as through EU consumer lobby groups.	**Sample bias**: Response to the survey would have mainly been provided by individuals who engage in electricity regulatory and policy matters. **Strategic response:** In addition, knowledge that the survey may inform regulation and policy may have led to strategic responses, e.g. over-estimating value of supply in order to promote vested interests.
Contingent valuation WTA	Given the intended applications of our primary research, and to ensure sufficient simplicity of the survey to encourage responses, we decided to use a contingent valuation approach, using only the WTA question form, where relevant.	**Limited scope for absolute analysis:** Previous literature suggests that contingent valuation and the use of WTA only can lead to (potentially significant) overestimates of value of supply. This means that analysis should not seek to draw conclusions in relation to absolute values. Only relative valuation between scenarios (e.g. notice and no notice) can be made.
Lack of incentive	No incentive was provided to participants to respond to the survey, or to answer truthfully. Responses were voluntary.	**Limited scope for absolute analysis**: This may exacerbate problems with drawing absolute conclusions as stated previously. **Strategic response:** It may also lead to a bias for those to respond to have some form of vested interest in outcomes.
Number of responses	In comparison with studies which use surveying as their primary method of measuring WTP/WTA or VoLL, our survey had fewer responses.	**Not suitable for detailed analysis in some areas of assumptions**: While the rate of response was sufficient to draw some high-level (and statistically significant) conclusions at EU and regional level, the number of responses does not allow for conclusions to be drawn at the national level, e.g. in relation to the substitutability factor.

Source: CEPA Analysis

5. MARKET SEGMENTATION

In this section we present the segmentation of electricity consumers that we have applied for the VoLL analysis. We have defined domestic consumers as a single homogeneous group but have segmented non-domestic consumers in order to conduct more detailed analysis.

Based on our analysis of the literature and of the data available for analysis, we have segmented non-domestic consumers into 13 sectors. 10 of these sectors relate to the manufacturing industry and we identify three 'other' sectors. These 13 sectors are summarised in Figure 5.1 below.[28]

Figure 5.1: Sectors for our segmentation of non-domestic consumers

Manufacturing industry	Other sectors
• Manufacture of basic metals • Chemicals and petrochemicals • Non-metallic minerals • Food and tobacco • Textile and leather • Paper, pulp and print • Wood and wood products • Transport equipment • Machinery • Construction	• Transport • Agriculture, forestry and fishing • Services

Source: CEPA analysis

Overall, we consider the consumer segmentation presented above to provide a suitable level of disaggregation. Our segmentation aligns with good practice from previous literature. Overall, we believe that it captures a sufficient level of heterogeneity of consumers to enable robust analysis.

However, we note that the 'Services' sector may represent a relatively heterogeneous collection of consumers. Data availability has limited the majority of national VoLL studies from disaggregating Services consumers and this limitation is also reflected in EU-level data. The level of differentiation in GVA and consumption within this sector may suggest that it would be preferable to disaggregate this sector further if sufficient granularity of data was available.

In order to conduct more disaggregated analysis, we have tried to find EU national statistical agencies that present consumption data for the Services sectors at a disaggregated level. In four cases, we have identified this consumption data and have been able to map this onto the GVA labels used by Eurostat with a sufficient level of accuracy. We do, however, urge caution

[28] VoLL for the mining and quarrying sector was also analysed but is not reported due to data limitations.

with interpretation of these results given a lower level of confidence in the quality of data and consistency of sector definitions in comparison to our headline estimates.

We set out our findings in ANNEX H.

6. FINDINGS

This section presents our VoLL findings for domestic and non-domestic consumers. Each subsection is organised as follows:

- First, we outline the assumptions we have used for our VoLL estimates based on previous literature and our primary research.
- Second, we present our headline annual VoLL estimates for each MS.
- Third, we analyse the relationship between duration of a supply interruption and provision of notice on our VoLL estimates.

We present our findings for TSD separately in Section 6.3.

6.1. Domestic consumer VoLL findings

The section below discusses our assumptions and presents our headline domestic VoLL estimates for each MS.

6.1.1. Refinement of assumptions using primary research

Our primary research was used to refine the assumptions that were applied within our headline VoLL estimates. We also conducted detailed analysis of available data (e.g. on time use of individuals) to confirm these assumptions.

Categorising MS

We have used our primary research to assess whether there is sufficient evidence to differentiate our domestic VoLL assumptions across relative income level and geographical location. The groupings that we applied are presented below. Geographic regions are based on the standard United Nations Statistics Division geoscheme methodology[29]. We have defined an MS as having 'relatively high' income if its purchasing power adjusted GDP per capita is at or above the median of all MS.

[29] https://unstats.un.org/unsd/methodology/m49/

Figure 6.1: Categorisation of Member States by region

Northern Europe	Eastern Europe	Southern Europe	Western Europe
• Denmark	• Bulgaria	• Croatia	• Austria
• Estonia	• Czech Republic	• Cyprus	• Belgium
• Finland	• Hungary	• Greece	• France
• Ireland	• Poland	• Italy	• Germany
• Latvia	• Romania	• Malta	• Luxembourg
• Lithuania	• Slovakia	• Portugal	• Netherlands
• Sweden		• Slovenia	
• UK		• Spain	

Source: United Nations Statistics Division

Figure 6.2: Categorisation of Member States by income

Relatively high income	Relatively low income
• Austria	• Bulgaria
• Belgium	• Croatia
• Denmark	• Cyprus
• Finland	• Czech Republic
• France	• Estonia
• Germany	• Greece
• Ireland	• Hungary
• Italy	• Latvia
• Luxembourg	• Lithuania
• Malta	• Poland
• Netherlands	• Portugal
• Spain	• Romania
• Sweden	• Slovakia
• UK	• Slovenia

Source: CEPA analysis

Substitutability factor

Using our primary research, we explored assumptions in previous research where a substitutability factor of 50% is generally applied[30]. Our primary research provided evidence to suggest that this factor was an underestimate. It suggested a substitutability factor of 59.4% on average across all respondents. This was a statistically significant difference from the 50% assumption employed previously.

[30] E.g. Growitsch et al. (2013), Leahy and Tol (2013) and Shivakumar et al. (2017),

Table 6.1: Reported substitutability factors, domestic survey

	Disaggregation	Responses	Average substitutability factor
Overall		**609**	**59.4%**
Region	Northern Europe	145	63.1%
	Eastern Europe	176	58.9%
	Southern Europe	91	58.0%
	Western Europe	197	57.9%
Income	Relatively High	368	59.6%
	Relatively Low	241	59.1%

Source: CEPA analysis

We also wanted to explore whether the substitutability factor differed depending upon region. We found that consumers within MS classed as Northern stated a slightly higher substitutability factor compared to the rest of Europe. While Northern Europe reported an average substitutability factor of **63.1%**, the rest of Europe had an average of **58.3%**. This difference is statistically significant and has been used to refine our baseline assumptions.

This is consistent with the observation that Northern Europe typically experiences colder weather and longer periods of darkness. This may explain the higher substitutability factor – which means individuals' leisure is more dependent on electricity.

No statistical difference was found between MS of different income levels. Furthermore, the small sample size in relation to non-employed individuals means we are unable to robustly differentiate the substitutability factor between employed and non-employed individuals.

Time spent on leisure activities

Another assumption which feeds into the calculation of VoLL is the number of hours in the day spent on leisure activities[31]. Previous literature has estimated that 11 hours of the day is spent on sleeping and personal care (e.g. Growitsch et al. (2013)) with the remainder shared between work and leisure activity. We used data on time use available for 14 countries from Eurostat to explore this assumption. This analysis demonstrated that variability from one country to the next is low with average time spent on personal care of 11 hours and 19 minutes[32]. As a result, we consider that the previously applied assumption of 11 hours is justified for average time spent sleeping and on personal care.

[31] Defined in the broad sense of leisure activity – i.e. all time not spent working, sleeping, eating or on personal care.

[32] Eurostat, source I.D. [tus_00age].

Non-employment factor

In order to account for the fact that those who are not in employment are likely to have a lower value of leisure[33], we must determine a 'non-employed factor'. Our primary research collected only a limited number of responses from non-employed individuals (38). As a result, we did not identify a sufficient reason to deviate from the 50% non-employed factor applied in the previous literature. For this reason, we have continued to apply a non-employed factor of 50%. However, we have conducted sensitivity analysis around our 50% baseline assumption by considering the impact on VoLL if the non-employed factor is taken to be 25% and 75%. We set out our findings in ANNEX I.

Summary of assumptions used for domestic VoLL

Table 6.2 summarises the assumptions that we apply for domestic consumers.

Table 6.2: Final domestic assumptions

Assumption	Role of primary research	Impact on analysis
Substitutability factor (domestic)	Test previously applied assumptions and assess regional diversity of substitutability factor.	Baseline refined from 50% to **63.1%** for Northern MS and **58.3%** for other remaining MS.
Time spent on leisure activities	Test findings from the data and from previous research in relation to time spent on leisure activities.	Baseline retained at 11 hours personal care time.
Non-employed leisure value time	Test previously applied assumptions of non-employed leisure time.	Baseline of 50% retained due to limited non-employed sample. Sensitivities conducted using 25% and 75% non-employed factors.

Source: CEPA Analysis

6.1.2. Annual average domestic VoLL estimates

Applying the methodology described in Section 4 and using the assumptions above, we arrive at the following domestic VoLL estimates by region. Full results for each MS are provided in ANNEX G.

[33] As a result of having more leisure time and a lower income on average.

Table 6.3: Headline domestic VoLL estimates

Region	Annual average domestic VoLL (€/kWh)		
	Minimum	Median	Maximum
Northern	4.62	**5.41**	15.90
Eastern	1.50	**4.03**	6.26
Southern	3.15	**6.04**	11.34
Western	6.92	**11.01**	22.94

Source: CEPA analysis

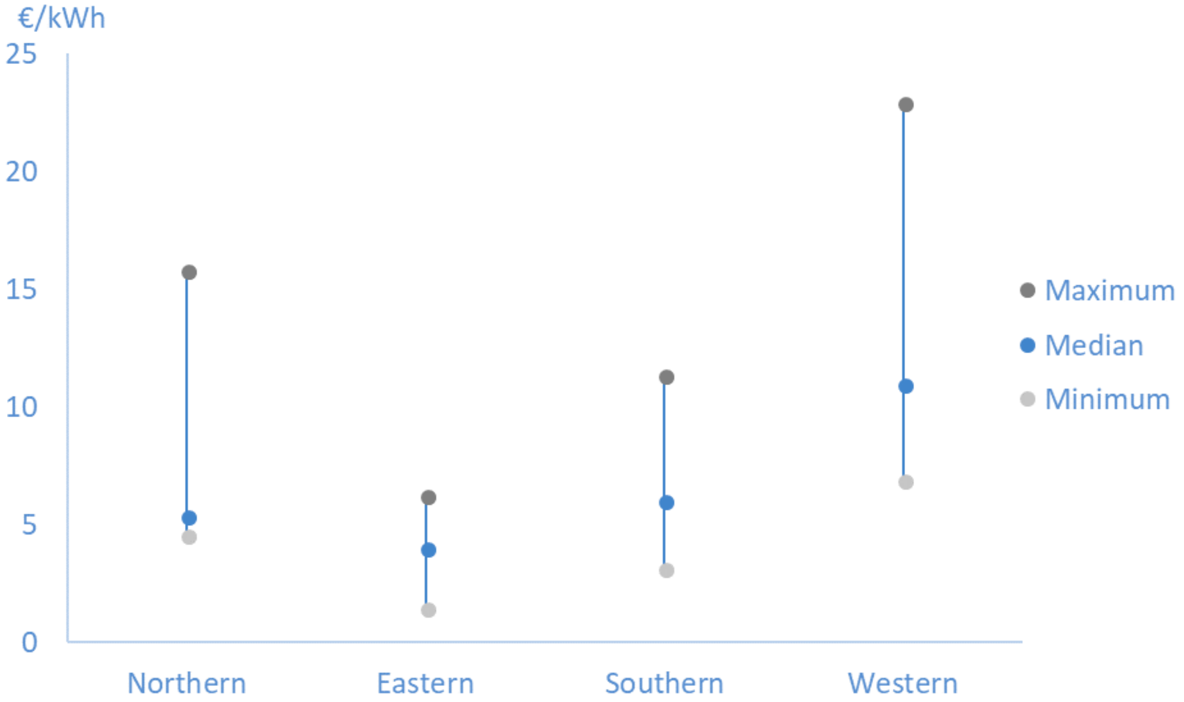
Estimated domestic VoLLs range from 1.50 €/kWh in Bulgaria to 22.94 €/kWh in the Netherlands. The median value across all of Europe is 6.04 €/kWh.

Our results are broadly in line with those observed in previous studies, summarised in our literature review (Section 2.3). Generally, we see that individuals in Western European MS exhibit higher VoLLs. As this region is comprised mainly of countries with per capita incomes above the median level, this is consistent with the hypothesis that VoLL increases with income. Eastern European MS that are comprised of a greater proportion of incomes below the median level have the lowest median VoLL.

Additionally, there appears to be evidence that individuals living in more northern areas, where the climate is typically colder and darker have higher VoLLs. For example, of the Western MS, the country with the highest VoLL, the Netherlands, is also one of the furthest north while France which (with the possible exception of Austria) covers a region which is the furthest south has the lowest VoLL.

Comparing MS with below median VoLL in Northern and Southern or Eastern Europe, we observe a similar trend. While Estonia, Latvia and Lithuania have the lowest VoLL in Northern Europe, they are all above the median VoLL experienced in Eastern Europe.

Figure 6.3: Estimated domestic VoLL ranges for EU member states by region



Source: CEPA analysis

Comparison against previous literature

We have compared our results against recent VoLL estimates for European MS where VoLL has been derived within a national study. The results are summarised in Table 6.4 below[34]. After adjusting for inflation, our VoLL estimates are broadly in line with those found within the literature.

Results for the studies carried out within Austria and Ireland are exceptions to this close alignment. We explain these differences by considering the approach and assumptions within each study.

In the case of Austria, Reichl et al. (2012) uses an approach based on WTP only. As has been noted elsewhere in this report, there are typically large discrepancies between WTP and WTA, with WTP often resulting in significantly lower estimates. Other studies have either taken the average of the WTP and WTA estimates (see Betazzi and Fumagalli (2005)) or have determined that WTA is most appropriate for the context of interruptions in the EU (see London Economics (2013)). This suggests that the VoLL results from the Austrian national study may be underestimates relative to approaches regularly found within the literature.

Conversely, Leahy and Tol's (2010) estimate of VoLL in Ireland is significantly higher than ours. This can be explained by the fact that Leahy and Tol assume substitutability factor of 100%.

[34] In some cases, authors provide a range of VoLL estimates, differentiating by time of day/year or by duration of the interruption, for example. Where only one result has been derived by the author(s), we take this as the comparator. Where this is not the case, we have considered the context which is most appropriate – e.g. results for a one-hour outage.

This contrasts with the broad consensus in the literature which has used a 50% substitutability factor. Our primary research has developed an evidence base for the substitutability factor for the first time and suggests this to be 63.1% for Ireland (Northern Europe). If we applied a 63.1% substitutability factor to Leahy and Tol's estimates, we would derive an estimate (€15.6/kWh) which, though still a little higher than may be expected, is more in line with our estimates (€11.5/kWh) and those found in other studies across Europe.

These two studies provide examples of the importance of the study approach and assumptions used to derive VoLL estimates. They highlight the importance of estimating VoLL based on a consistent and objective approach, such as that used within this study.

Table 6.4: Comparison of domestic VoLL against a sample of national studies[35]

MS	Study author(s)	Year	CEPA (€/kWh)	National study (€/kWh)
Austria	Reichl et al.	2012	9.01	2.8[36]
Cyprus	Zachariadis and Poullikkas	2012	6.19	9.78
Germany	Growitsch et al.	2013	12.41	13.32[37]
Italy	Bertazzi and Fumagalli	2005	11.34	12.69[38]
Republic of Ireland	Leahy and Tol	2010	11.52	24.7
Spain	Linares and Rey	2012	7.88	8.78
U.K.	London Economics	2013	15.90	8.93 – 15.17[39]

Source: Various national studies and CEPA analysis

6.1.3. Impact of duration

We now summarise our analysis of the impact of duration using data collected from our primary research. This research was designed to draw conclusions in relation to the *relative* valuation of WTA in response to outages of changing duration. Given the context and design of the survey, we intentionally refrain from drawing conclusions in absolute terms.

Unsurprisingly, our research found that overall WTA increases as the length of an outage increases. Based on the durations of outage considered in the survey (20 minutes, two hours and two days[40]), the increase in WTA over time is not linear. For example, while a two-day

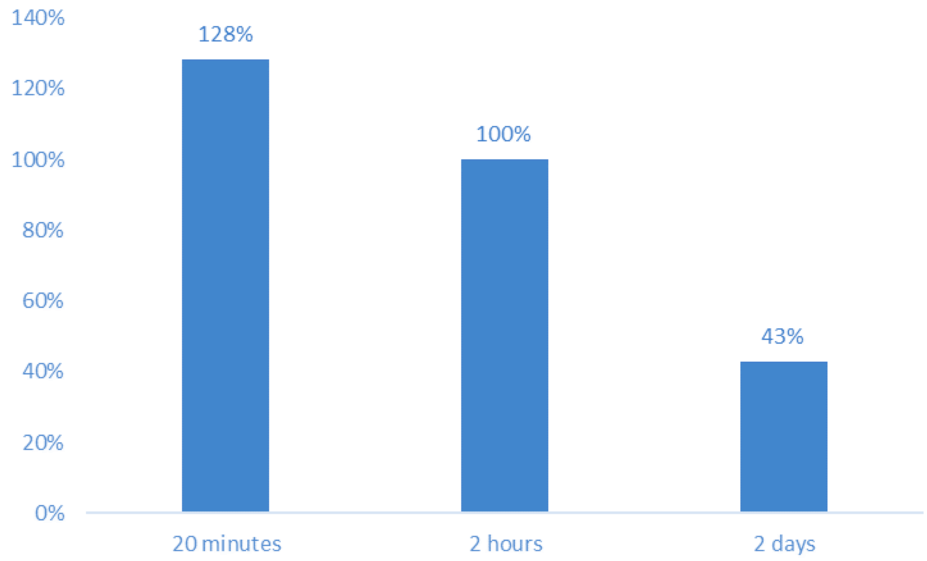
[35] Comparator values from national studies have been inflation adjusted to 2015 Euros.
[36] VoLL is specified in this report for a winter morning.
[37] Result for the Federal Republic of Germany.
[38] Bertazzi and Fumagalli identify a broad range of VoLL estimates depending on whether WTP or WTA is used and depending on duration of the outage. The stated figure represents the average of the WTA and WTP estimates for a one-hour outage as per the triangulation approach recommended by CEER.
[39] London Economics identify a range of estimates using both WTP and WTA. The stated figure is the range of the London Economics' preferred WTA model estimates for a one-hour outage at various times of the year.
[40] These duration scenarios were selected for two reasons: 1. We limited duration scenarios to three to maximise rate of response and sample size, 2. A duration scenario of 2 days was explicitly required by ACER within the terms of reference for the study. We elaborate on our rationale in Annex F of this report.

outage is 24 times as long as a two-hour one, domestic consumers have a WTA of approximately 10 times the two-hour level.

To explore this relationship, we consider the average WTA per hour, as this approximates the *marginal* cost of an outage. As the duration of an outage increases, domestic consumers report a falling marginal cost. The WTA per hour for a twenty-minute outage is around 130% of that for an outage lasting two hours. WTA for a two-day outage is only 43% of that for a two-hour outage (Figure 6.4). This is consistent with the interpretation of an initial 'annoyance factor' and damage costs which decrease (relatively speaking) as consumers become better able to adapt with increasing duration of the outage. It is also consistent with the majority of previous literature which has found a similar trend (see Table 2.2).

While alignment with the general consensus in the literature suggests validity of our primary research in relative terms, we note that the results of studies which use survey-based methods inevitably depend to some extent on the design of the questionnaire. Regarding the relationship between WTA and duration, our results add further evidence to suggest a decreasing marginal WTA.

Figure 6.4: Domestic WTA per hour relative to 2-hour outage

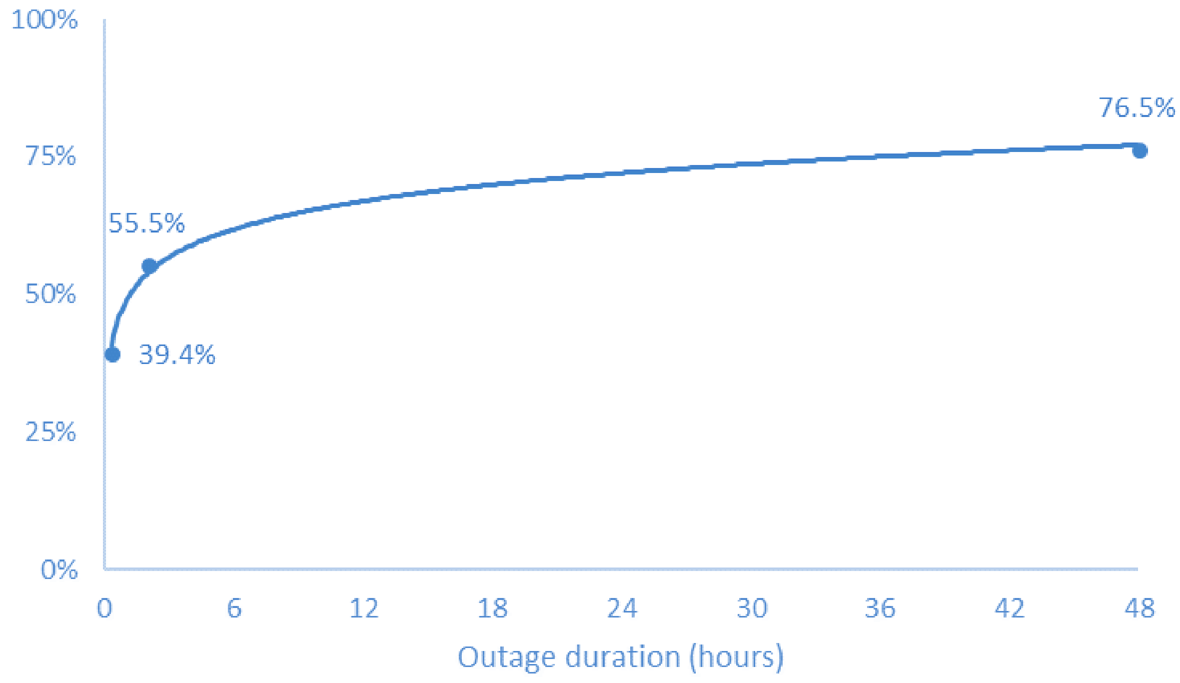


Source: CEPA analysis

6.1.4. Impact of provision of notice – the 'notice factor'

As expected, our primary research found that the WTA for an outage of a given duration falls when consumers are notified ahead the outage. All else being equal, this will translate to the cost of the outage falling – VoLA will be lower than VoLL. However, our research also suggests that, as the duration of the outage increases, the difference between WTA with and without notice reduces. In other words, the provision of notice is less beneficial for consumers as duration increases, so we can expect VoLA to be closer to VoLL. In effect, the notice factor increases with duration (i.e. notice is less beneficial), as shown in Figure 6.5.[41]

Figure 6.5: Implied notice factor over time



Source: CEPA analysis

We have explored the impact of applying our primary research findings to our VoLL estimates. For the purposes of calculating VoLA, we consider the notice factor in response to a two-hour outage. Therefore, we apply a **55.5%** notice factor (i.e. VoLA for domestic consumers will be just over half the magnitude of VoLL). For example, our estimated domestic VoLL for Austria and the UK are 9.01 and 15.90 €/kWh respectively. With the provision of one-day of notice, applying the notice factor implies a VoLA of 5.00 and 8.83 €/kWh respectively. The full results are available in ANNEX G.

6.2. Non-domestic consumer VoLL findings

This section presents our non-domestic VoLL findings, and includes our headline non-domestic VoLL estimates for each MS.

6.2.1. Assumptions following primary research

Categorising sectors

The sample size observed for non-domestic consumers (124) did not allow for differentiation of consumers at a very disaggregated level. We have therefore explored results by considering

[41] The notice factor is 'implied' as it is calculated indirectly from consumers' WTA responses in relation to equivalent supply interruption events, but with and without the provision of one day of notice.

differentiation between consumers in the Industrial and Services sectors but have not drawn conclusions of individual sectors within these categories.

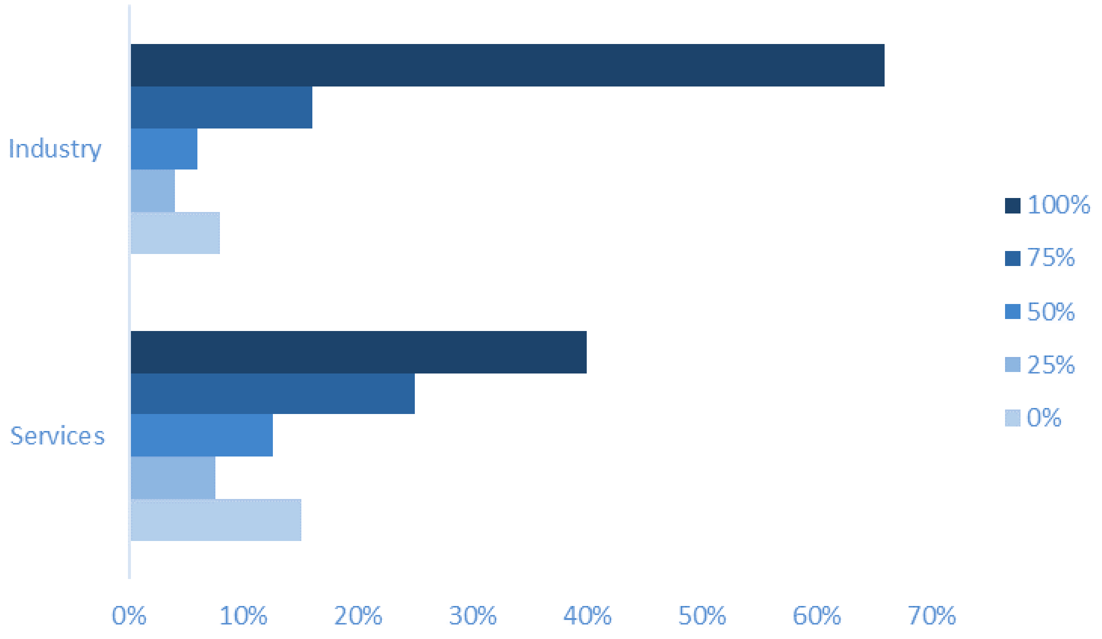
Differences between SMEs and larger firms were also analysed using our primary research. We used the European Commission definition of an SME as an enterprise "*which employs fewer than 250 persons and which has an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million*".[42]

Substitutability factor

For non-domestic consumers, previous studies have applied a substitutability factor of 100% based on the belief that non-domestic consumers may be highly dependent on electricity and in the absence of detailed analysis.

Figure 6.6 shows the distribution of responses of non-domestic consumers to our survey. We can observe a wide range of reported substitutability factors for both Industrial and Services consumers but with a sizeable proportion stating a 100% factor in both cases.

Figure 6.6: Substitutability factor distribution, non-domestic survey



Source: CEPA analysis

In Table 6.5, we present the average substitutability factors, differentiated between Industrial and Services consumers and between SMEs and non-SMEs.

[42] EU recommendation 2003/361.

Table 6.5: Reported substitutability factors, non-domestic survey

	Disaggregation	Responses	Average substitutability factor
Overall		**103**[43]	**75.2%**
Type of business	Industry	51	80.9%
	Services	44	68.2%
Size of business	SME	29	74.1%
	Non-SME	65	76.2%

Source: CEPA analysis

We find that Industrial consumers report a higher substitutability factor than Services consumers. This difference is statistically significant. This may be expected, as a higher substitutability factor implies Industrial consumers are less able to shift away from production methods which are reliant on electricity. Based on the results of this survey, we use a substitutability factor of **80.9%**, for Industrial consumers and **68.2%** for those in the Services sectors for our baseline VoLL analysis.[44]

Although the size of our sample leads us to base our VoLL estimates on assumptions calculated for the Industry sector as a whole, it is important to note that greater disaggregation could be justified (and differences may even be present at an individual consumer level within any one sector)[45]. We note that more than half of Industrial consumers reported a substitutability factor of 100% and that, while based on a small sample, some industries reported average factors of above 90% (e.g. Chemicals and Petrochemicals, Machinery, and Manufacture of Basic Metals).

We examined whether there was any difference in reported substitutability factors based on the size of the business responding to the survey. Although SME firms did report a slightly lower average substitutability factor than other firms, this difference was not statistically significant, and is not large enough to justify specific treatment of SMEs when estimating VoLL. As such, our assumptions do not differentiate between SME and non-SME consumers.

Summary of assumptions used for non-domestic VoLL

As with domestic consumers, our primary research was designed to refine previously applied assumptions to apply to our headline average annual VoLL estimates. Using our primary research, we refined assumptions of the substitutability factor to identify separate values for Industrial and Services consumers as presented in Table 6.6.

[43] NB: Not all respondents were defined as Industrial or Services. Some reported that they were 'Other'. In addition, some respondents chose not to declare if they were an SME or not.

[44] Agriculture, Forestry and Fishing has been assigned with the Services substitutability factor and Transport assigned with the Industry substitutability factor.

[45] Given that a sizeable majority of Industry consumers have stated a substitutability factor of 100%, we have performed sensitivity analysis using this as the substitutability factor and present our findings in ANNEX A.

Table 6.6: Finalised non-domestic assumptions

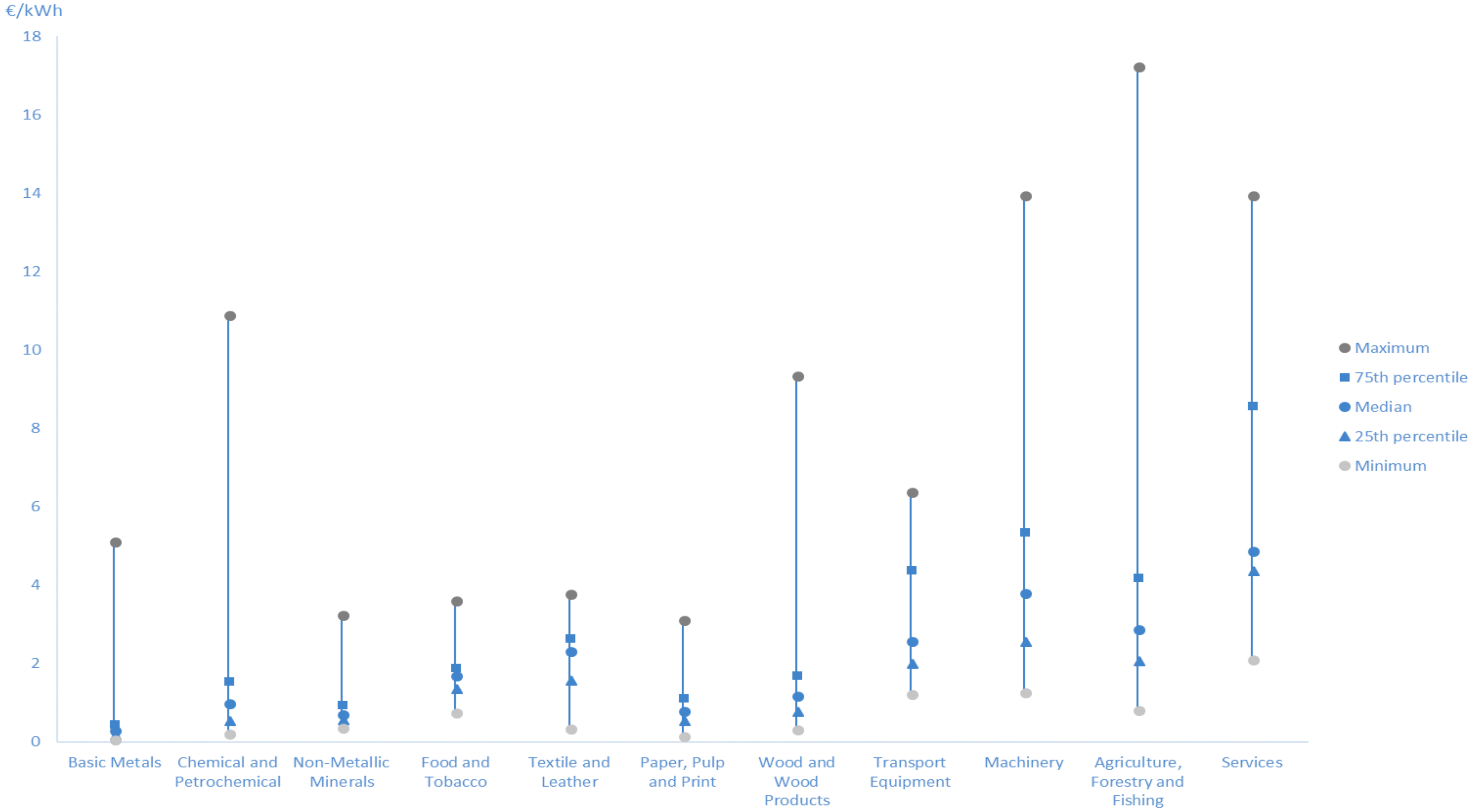
Assumption	Role of primary research	Impact on analysis
Substitutability factor (non-domestic)	Test previously applied assumptions and assess differentiated substitutability factor on a range of consumer types.	Baseline refined from 100% to **80.9%** for industry and **68.2%** for services.

Source: CEPA analysis

6.2.2. Annual average non-domestic VoLL estimates

Applying the methodology described in Section 4 and the assumptions above, we arrived at our headline non-domestic VoLL estimates. Figure 6.7 summarises the majority of our non-domestic estimates (findings for the Construction industry and the Transport industry are presented separately in Figure 6.8). The range of estimates reflects the difference in VoLLs across MS. The median estimated non-domestic VoLLs range from 0.31 €/kWh for the manufacture of Basic Metals to 17.76 €/kWh in the construction sector. With the exception of the Construction sector, VoLL for non-domestic consumers in the Services sector tends to be higher than for firms in Industry. This is true for the vast majority of EU MS. Detailed results by MS are available in ANNEX G.

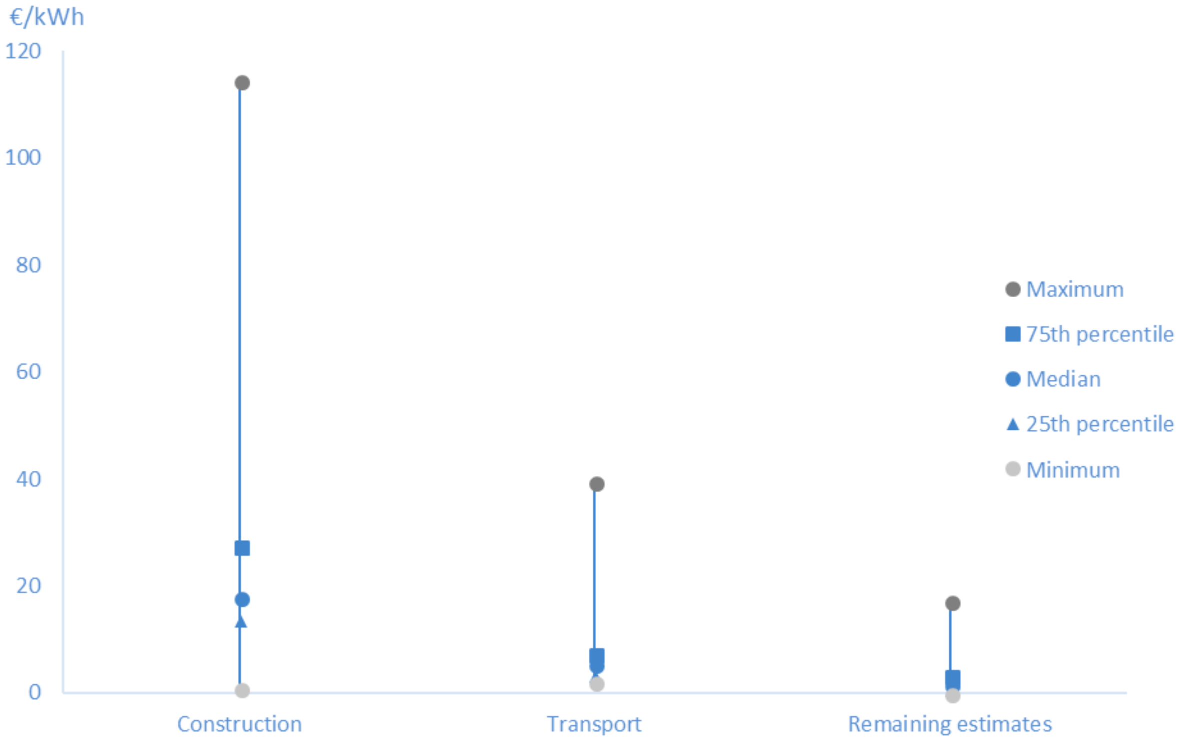
Figure 6.7: Estimated non-domestic VoLL ranges across all EU MS by sector (excluding Construction or Transport)



Source: CEPA analysis

As the Construction and Transport sectors include significantly higher estimates, these are presented in Figure 6.8. We present these ranges alongside a summary of the remaining sectors for comparison:

Figure 6.8: Estimated non-domestic VoLL ranges across all EU MS by sector (Construction and Transport)



Source: CEPA analysis

Our results are broadly in line with those observed in previous studies, as set out in our literature review (Section 2.3) and summarised below. As with other studies, we identify a higher median VoLL for the Services sectors (including Agriculture, Forestry and Fishing) than for heavy industry and manufacturing sectors.

Our results also show that the Construction sector demonstrates the highest median VoLL, with results spanning a broad range (e.g. identified VoLL for the Construction industry ranges from 1.03 €/kWh to 113.0 €/kWh). Where previously explored, these ranges are consistent with previous research. For example, our estimate of 113.0 €/kWh for the Construction sector in Cyprus is in line with an estimated VoLL of around 120 €/kWh found in Zachariadis and Poullikkas (2012). Similarly, the relatively high VoLL estimate for the Construction sector in the UK is supported by the findings of Reckon (2012).

We identify three hypotheses which may help to explain the potential for high VoLL estimates in some industries and within some MS:

1. **The normalisation of VoLL in cases of low consumption.** It is important to emphasise that the concept of VoLL is a measure of the cost of an outage *per unit of electricity*

consumption. Therefore, all else equal, spreading a given outage cost over a lower level of consumption will lead to higher levels of VoLL. The Construction sector may present an example in which a high level of output can be produced using a relatively low amount of electricity consumption. If this is the case, the high VoLL estimates would accurately reflect actual VoLLs.

2. **The criticality of input.** We note that the criticality of input[46] (which may be measured by our substitutability factor) may also be an important driver. Our primary research has considered reported substitutability factors of Industrial consumers across sectors. However, we have not been able to examine this at a high level of disaggregation within the Industrial sectors. Measurement of the substitutability factor in some of those sectors where a high level of VoLL is reported may reflect the fact that electricity is not as critical an input as for other sectors. For example, if electricity is less of a critical input for the Construction industry (leading to a low substitutability factor), the estimates of VoLL experienced in this sector may become more in line with that seen for other sectors.
3. **Data reporting.** In sectors with low levels of consumption, any discrepancies in the reported data may have a particularly pronounced impact on estimated VoLL. These discrepancies may result from the definitions used and inconsistencies between reporting against GVA as opposed to consumption. Alternatively, they may simply reflect errors/biases in reporting of the data.

Taking the example of the Construction sector, we expect that the results seen may result from some combination of the factors highlighted above. While low levels of consumption may lead to over-estimates for those countries which appear to be outliers (e.g. Cyprus), we note that the high median VoLL of the construction industry shows that our findings of a high VoLL are not limited to one or two MS. It is therefore likely that the high VoLL estimates of the Construction sector are appropriate to at least some degree, while the level of criticality used as an assumption for this industry may lead to a general trend of over-estimation. Detailed research into the substitutability factor of this industry would allow for greater understanding of these results.

Comparison against previous literature

As with our domestic VoLL results, we find our non-domestic VoLL estimates to be broadly consistent with recent national studies. Table 6.7 summarises estimates for Industrial consumers (not including Services). The ranges of our VoLL estimates generally encompass the aggregated estimates of previous studies. It should be noted that few studies consider non-domestic consumers at the same level of segmentation as measured in our study, hence point estimates are often provided, representing Industrial consumers as a whole[47].

[46] As discussed in London Economics (2013).
[47] This is why we provide a range of estimates in the table while most other studies are limited to point estimates.

Inconsistent segmentation definitions between studies also warrant caution when comparing estimates.

Table 6.7: Comparison of Industry VoLL against a sample of national studies[48]

MS	Study author(s)	Year	CEPA (€/kWh)	National study (€/kWh)
Cyprus	Zachariadis and Poullikkas	2012	0.45 – 5.45	2.06
Germany	Growitsch et al.	2013	0.41 – 6.09	1.81
Republic of Ireland	Leahy and Tol	2010	0.34 – 10.77	4
Spain	Linares and Rey	2012	0.28 – 4.76	1.49
UK	London Economics	2013	0.51 – 5.53	0.43 – 14.07[49]

Source: Various national studies and CEPA analysis

Table 6.8 provides a similar comparison for the Services sector. The fact that our results consistently appear to represent a slight underestimate can be explained by our incorporation of an evidence-based substitutability factor. While previous studies have typically assumed a substitutability factor of 100% for Services consumers, our primary research has suggested a substitutability factor of approximately 68.2%. If we remove the impact of this improved assumption, results of other studies align with ours (with the exception of Leahy and Tol (2010) which, as for Domestic and Industry consumers, appear somewhat high[50]).

Table 6.8: Comparison of Services sector VoLL against a sample of national studies

MS	Study author(s)	Year	CEPA (€/kWh)	National study (€/kWh)	CEPA (100% s.f.) (€/kWh)
Cyprus	Zachariadis and Poullikkas	2012	4.65	6.60	6.81
Germany	Growitsch et al.	2013	8.55	12.34	12.53
Republic of Ireland	Leahy and Tol	2010	13.97	13 – 14	20.48
Spain	Linares and Rey	2012	6.64	9.17	9.73

Source: Various national studies and CEPA analysis

[48] Comparator values from the national studies have been uplifted to 2015 Euros. With the exception of the UK study, the comparator values represent aggregate estimates for the manufacturing industry (excluding construction) as a whole, rather than a range from individual sub-sectors.

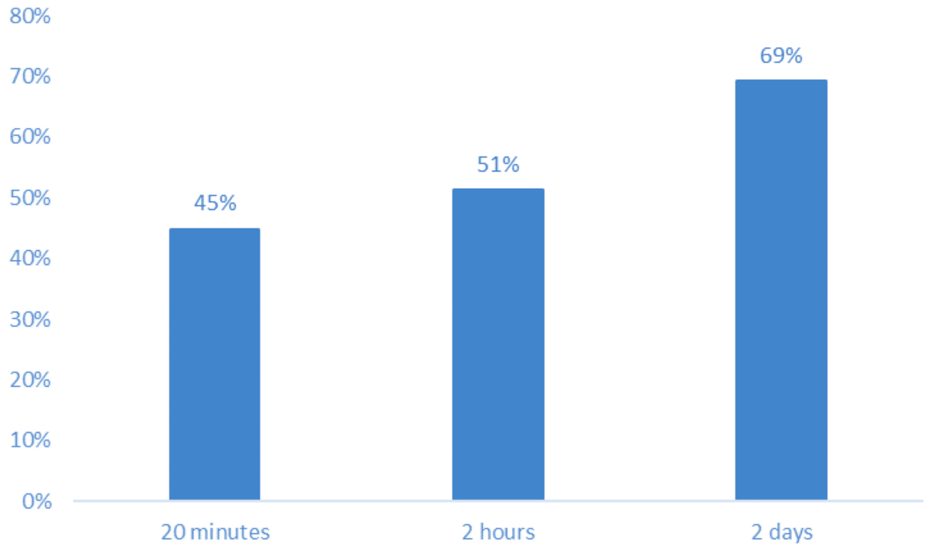
[49] The stated range is of disaggregated industrial sectors from both London Economics' 'capacity' and 'utilisation' methodological approaches.

[50] In combination with Domestic results, this suggests to us that the methodology applied by Leahy and Tol resulted in some form of bias towards overestimates relative to the literature and our findings.

6.2.3. Impact of duration and notice

Our findings for the impact of duration and the provision of notice follow a broadly similar pattern as described for domestic consumers. While WTA increases with the length of supply interruption, the WTA per hour (i.e. the marginal WTA) decreases with duration.

Figure 6.9: WTA as percentage of monthly bill, non-domestic survey



Source: CEPA analysis

Figure 6.9 shows how WTA for non-domestic consumers increases with duration of an outage. While the absolute WTA increases with duration, as with domestic consumers, marginal WTA decreases. In fact, marginal WTA falls at a significantly more pronounced rate than for domestic consumers, as shown in Figure 6.10. Relative to an interruption of two hours, a 20-minute duration WTA is five times higher per hour, while WTA per hour for a two-day outage is only 6% of that of a two-hour interruption. This steep decline in marginal WTA is consistent with the hypothesis that a supply interruption of even a very short duration may have a disproportionately high impact on the production methods of many non-domestic consumers[51]. Consumers may have also taken into account indirect costs such as damage to equipment and 'hassle factors'.

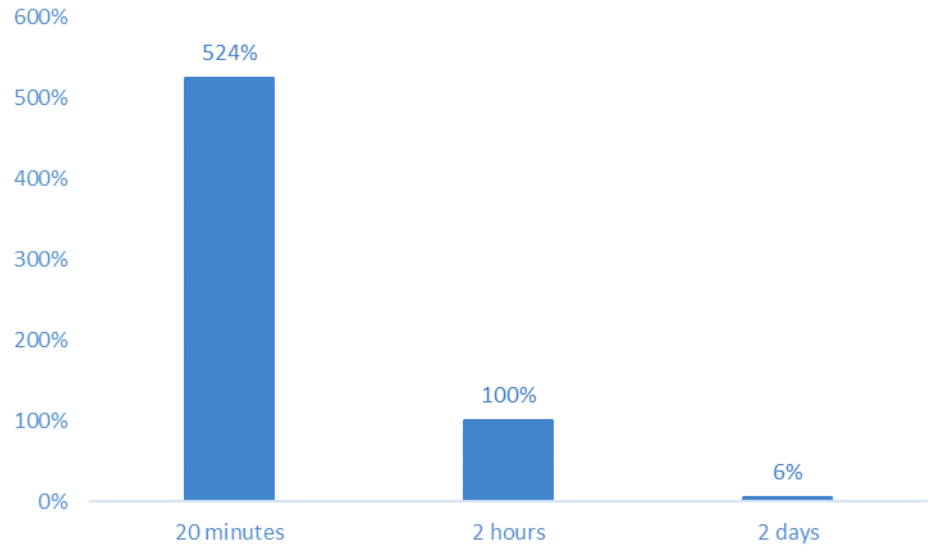
As is the case for domestic consumers, we consider that our findings support the evidence from previous literature that marginal WTP/WTA decreases with duration of outage. In addition, our results suggest that this relationship is more pronounced for non-domestic consumers. However, we again urge caution in drawing too directly in relation to the

[51] We also note that the form of question may have had an impact on the trend of WTA over time. While domestic consumers stated a WTA in currency terms, in order to allow for meaningful comparison of results, non-domestic consumers were required to respond with reference to a percentage of their monthly bill.

magnitude of this relationship[52]. This should be considered alongside other studies which have reported findings for the magnitude of this relationship (see Table 2.2).

Finally, we note the heterogeneity of non-domestic consumers in this area. While we may expect the majority to have a decreasing marginal WTA, certain types of consumer (e.g. refrigerated products) may demonstrate a different relationship.

Figure 6.10: Non-domestic WTA per hour relative to 2-hour outage



Our primary research also enabled us to consider the average notice factor for non-domestic consumers, as directly stated by respondents. Non-domestic consumers overall stated a notice factor of 70.9% for a two- to four-hour outage, compared to the roughly 60% estimated for domestic consumers. Consumers in the Industrial sector reported an average notice factor of **78.9%**, while for the Services sector the average was **61.9%**.

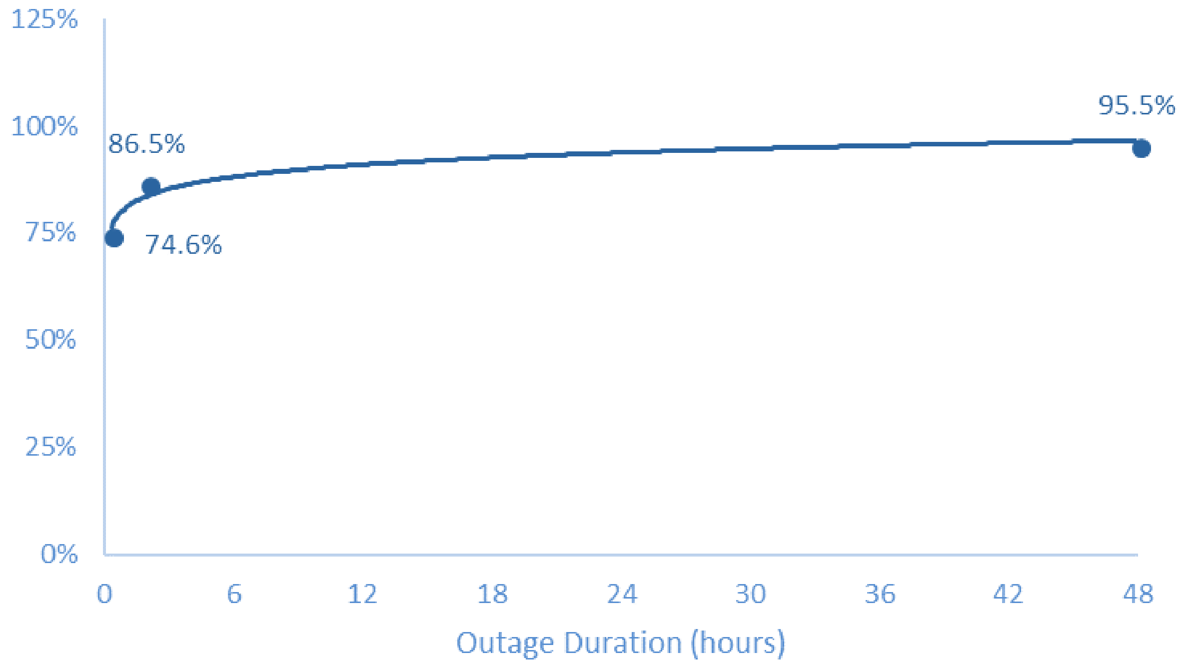
This suggests that non-domestic consumers, and Industrial consumers in particular, do not benefit as much from the provision of notice compared to domestic consumers. While notice does benefit non-domestic consumers to some extent, much of their output may be relatively fixed or dependent on electricity, even if notice is provided. However, consumers in the Services sector are slightly more able to make the shift away from electricity-dependent output if informed one day in advance.

We can estimate VoLA by applying the stated notice factors to our VoLL estimates. For example, in Austria, the estimates of annual VoLL for the Basic Metals and Services sectors are 0.90 and 10.43 €/kWh respectively. Applying the appropriate notice factors, produces VoLA estimates of 0.71 and 6.46 €/kWh for these two sectors.

[52] It is also important to note a slightly different methodology for stated values of domestic and non-domestic consumers. While domestic consumers were able to express WTA in open form, in order to ensure cross-comparability of very large and very small non-domestic consumers, these customers expressed WTA in the form of a percentage reduction on their monthly bill – this survey design follows previous literature.

Similar to domestic consumers, we also observe that the notice factor increases with the duration of the outage. However, a flatter line can be observed. This suggests that the level of disruption resulting from a short interruption appears to be much closer to that experienced under a longer interruption even where notice is provided.[53] This provides further support for the hypothesis that a short interruption has a disproportionately high impact on non-domestic consumers, even where notice is provided.

Figure 6.11: Implied Industrial notice factor over time, non-domestic survey



Source: CEPA analysis

[53] We urge some caution in interpreting these results given that the design of the non-domestic survey differed from the domestic survey. While domestic consumers were able to enter any value for WTA, non-domestic consumers were limited to stating a percentage of their monthly bill.

6.3. Time specific dependence (TSD) analysis

We have considered the impact of timing of an outage on consumers by defining TSD, which is a function of the demand factor of consumers at any point in time. This assumes that at high levels of consumption, consumers value electricity more highly.

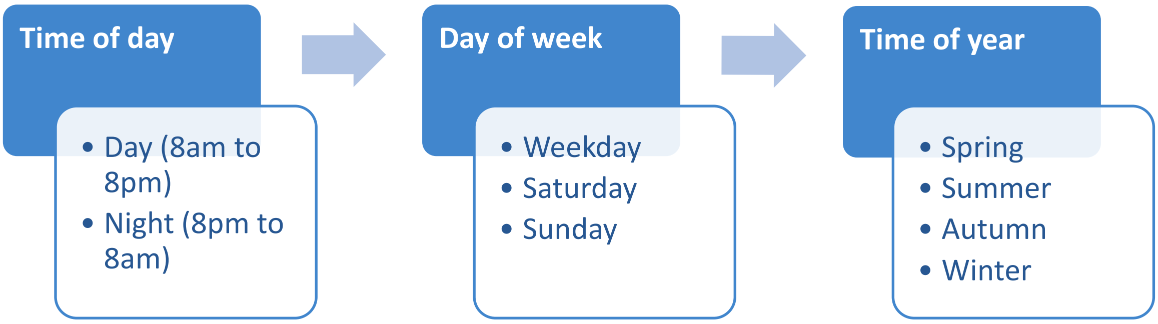
Given data limitations[54], our analysis at a pan-EU level depends on an assumption that the consumption profile is driven mainly by domestic consumers. This has allowed us to estimate TSD based on time of day, day of the week and season for all MS across the EU.

We have also conducted a case study of TSD for the UK, using consumption profile data sourced from ELEXON. Within this case study, we have been able to more accurately distinguish between the TSD of domestic and non-domestic consumers.

In both cases, TSD is evaluated relative to average electricity consumption, and in turn to the average VoLL estimates that have been discussed in the previous sections. Therefore, a demand factor higher than one leads to a higher than average TSD, and a demand factor lower than one leads to a lower than average TSD.

We aimed to capture three key time dimensions within the TSD analysis, summarised in the figure below.

Figure 6.12: Time dimensions of TSD analysis



Source: CEPA analysis

The remainder of this section is organised as follows:

- Firstly, we estimate TSD using hourly electricity consumption reported by ENTSO-E for each MS.[55]
- Secondly, we present our case study results for the UK using ELEXON representative load profiles, which enables us to produce TSD analysis at a more disaggregated level. By comparing results based on data from ENTSO-E against results from our case study, we can comment on the validity of the EU-wide analysis.

[54] We have not been able to obtain disaggregated consumption profiles from ENTSO-E which would allow for more granular analysis of TSD by sector.
[55] With the exception of Malta. Hourly electricity consumption is not available for Malta from ENTSO-E and the Maltese Statistical Office did not respond to our data queries.

6.3.1. Domestic TSD analysis using ENTSO-E hourly consumption data

Before calculating the TSD of consumers, we analysed differences in demand factors across MS using the ENTSO-E data. The results are summarised in the table below.

Table 6.9: Comparison of demand factors across MS

		EU Average	Northern MS Average	Eastern MS Average	Southern MS Average	Western MS Average
Time of Day	Day	109%	110%	108%	110%	108%
	Night	91%	90%	92%	90%	92%
Day of week	Weekday	102%	102%	101%	101%	102%
	Saturday	104%	104%	104%	104%	105%
	Sunday	94%	94%	95%	95%	94%
Time of Year	Spring	97%	98%	96%	94%	99%
	Summer	94%	87%	93%	104%	92%
	Autumn	100%	101%	101%	98%	100%
	Winter	110%	114%	110%	104%	109%

Source: CEPA analysis

Table 6.9 shows that there is a pronounced seasonal differentiation for Northern MS, which is seen to a lesser degree for Eastern and Western MS and is small for Southern MS. As we would expect, Northern MS have a higher dependence on electricity in the winter, whereas Southern MS have a flatter consumption profile over the year with less pronounced summer and winter peaks (potentially driven by cooling and heating respectively).

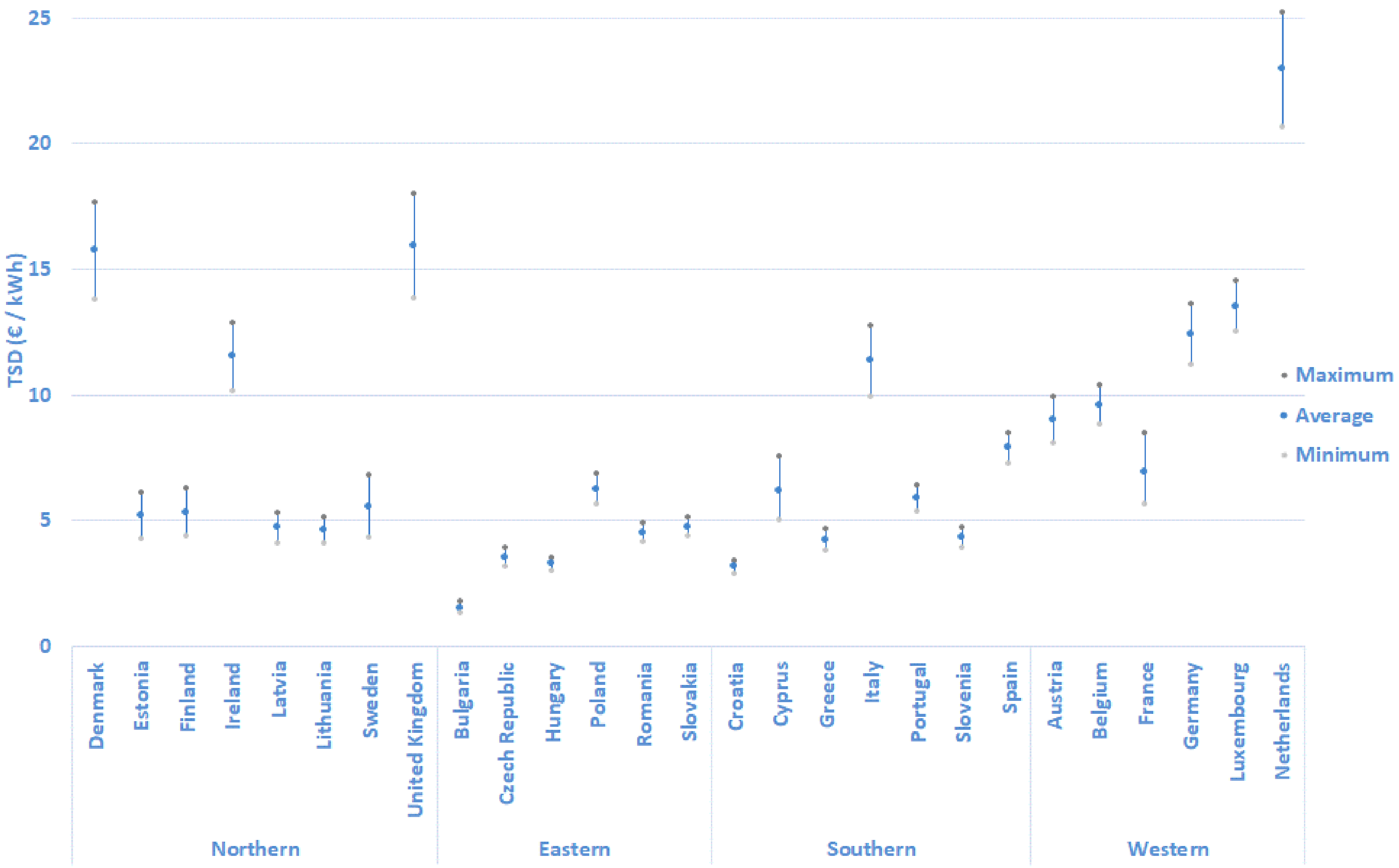
On the other hand, there appears to be less regional variation in terms of time of day and day of the week. As expected, there appears to be a significantly higher dependence on electricity during the day (which includes the evening peak) compared to at night. Regarding the day of the week, there appears to be significantly lower consumption of electricity on a Sunday than on any other day of the week, and this appears to be consistent across all EU MS. However, we expect that the latter may be driven by lower non-domestic consumption rather than lower domestic consumption as a significant proportion of industry is likely to stop production on a Sunday. We test this assumption in our UK case study.

Figure 6.13 translates the demand factor analysis above into domestic TSD ranges for each EU MS.[56] For Northern MS, the higher TSD within the range are experienced during the day in the winter. These ranges can be relatively large. For example, in Sweden, the maximum TSD witnessed in winter is approximately 24% higher than the average headline VoLL figure experienced on average in the year.

We generally see a smaller range of values for Southern MS where the higher values may reflect summer or winter consumption. Eastern and Western MS also have relatively small ranges with some notable exceptions. For example, results suggest that consumers in the Netherlands have a wide range of TSD, potentially reflecting the wider seasonal variations in consumption compared to other Western EU counterparts.

[56] The only exception being Malta, where hourly consumption data is not available.

Figure 6.13: Domestic consumer TSD ranges for EU MS



Source: CEPA analysis

6.3.2. Disaggregated TSD analysis – UK case study

To explore TSD of consumers at a disaggregated level, we have differentiated TSD by domestic and non-domestic consumption for the UK by making use of the representative load profiles constructed by ELEXON. These cover different types of electricity consumers in the UK (domestic, non-domestic, and non-domestic maximum demand customers) who have historically been settled without the use of half-hourly metering.[57]

Using these load profiles, we have calculated demand factors for domestic, industry and services consumers. Based on the definitions set by ELEXON, we used Profile Class 1 (Domestic Unrestricted Meters) to represent domestic consumers, Profile Class 3 (Non-Domestic Unrestricted Consumers) to represent services, and a weighted average of profile Classes 5 to 8 (Non-Domestic Maximum Demand Customers) to represent industrial.[58, 59] Using this information, we constructed a set of demand factors using the same approach employed previously. In the table below, we present these demand factors alongside those found for the UK based on the ENTSO-E data as used for the EU-wide analysis.

Table 6.10: Domestic, Services and Industry UK demand factors

		UK (section 7.1)	Domestic	Services	Industry
Time of Day	Day	111%	120%	130%	120%
	Night	89%	80%	70%	80%
Day of week	Weekday	103%	98%	128%	115%
	Saturday	104%	98%	93%	96%
	Sunday	94%	104%	79%	89%
Time of Year	Spring	100%	97%	98%	98%
	Summer	87%	87%	91%	94%
	Autumn	100%	97%	94%	99%
	Winter	113%	119%	118%	110%

Source: CEPA analysis

We can draw some immediate conclusions by comparing the demand factors for the UK identified using the ENTSO-E data and the UK specific data. Seasonal demand factors are a

[57] More details can be found at https://www.elexon.co.uk/operations-settlement/profiling/.
[58] The weights we applied were obtained directly from ELEXON on request.
[59] We accept that this mapping of consumption profiles is imperfect. In practice, some Industrial consumers may not be classed as Maximum Demand (Profile Classes 5-8) and some Services consumers may have very high levels of consumption. However, this mapping is considered to be a sufficiently accurate proxy for the purposes of this case study.

very close match, though the ENTSO-E data appears to represent an underestimate of the winter demand factor.

Factors based on time of day align to some degree. However, again, the ENTSO-E data may represent an underestimate of the differentiation of consumption of domestic consumers between night and day.

It appears that the demand factors based on the day of the week are inconsistent between the ENTSO-E pan-EU data and the ELEXON UK specific data. This effect may result from the fact that the national demand trends over the course of the week are influenced by the consumption of the Industrial and Services sectors, and hence that weekday demand factors are an overestimate and weekend demand factors an underestimate within the ENTSO-E data[60].

This may have implications for our consideration of the pan-EU data used for our overall TSD analysis. It suggests that the seasonality of TSD within the data is a relatively accurate reflection of domestic TSD and that this holds for analysis of TSD comparing day and night estimates to a lesser degree.

However, it questions the assumption that TSD in the EU over the week is driven by domestic consumers. In reality, the consumption of the Industrial and Services sectors needs to be accounted for when considering weekly TSD profiles.

[60] While this analysis is to some extent specific to the UK, we note that the trends observed (e.g. the contribution of consumption from the non-domestic sectors during the week but not at the weekend) are likely to apply across the EU.

7. CONCLUSIONS

In this study, we have developed a set of VoLL estimates covering all consumers in EU MS for the first time. By using a common and objective methodology, our estimates can be compared from one country to the next. We have also presented VoLL figures disaggregated by consumption sector to allow for more informed policy and decision making.

Building on previous research, we have refined a number of key assumptions which feed into these calculations by making use of our literature review, data analysis and primary research. We have also considered the impact of duration, notice and timing of an electricity interruption on VoLL, using a range of analytical techniques.

Substitutability factor and headline VoLL estimates

Making use of primary research, we have measured for the first time, the dependence of consumers across the EU on electricity, which we have defined as the substitutability factor.

For domestic consumers, our results show that this factor is somewhat higher than assumptions made in previous research. We also find that geographic location influences dependence. Domestic consumers in northern Europe express a higher (and statistically significant) substitutability factor compared to the remaining MS.

For non-domestic consumers, we identify a significantly higher substitutability factor than for domestic consumers. We note that many Industrial consumers express 100% dependence on electricity for productive output. While based on a limited number of responses (just over 100), our findings suggest relatively large differentiation between the level of dependence of consumers in the Industry sector as opposed to those in the Services sector.

Combining these substitutability factors with our analysis of EU data, we have developed VoLL estimates for a range of consumers across the EU. Our estimates align well with the previous literature. We observe a range of VoLL estimates for domestic consumers between €1.50/kWh for Bulgaria and €22.94/kWh for the Netherlands.

For non-domestic consumers, the median range is similar. We identify a median value of less than €1/kWh for a number of industries but a median value of €17.76/kWh for the construction industry. However, some of these sectors – particularly the construction industry – demonstrate significant outliers of up to €113.00/kWh.

The high VoLL estimates seen for the construction industry, including the presence of outliers, aligns with previous research[61]. We have postulated three hypotheses to explain these results. We emphasise the point that the normalisation of VoLL using consumption should lead to high VoLL estimates where a high output is produced using a relatively low level of electricity consumption. However, we also note that the criticality of input, which may be

[61] E.g. Reckon LLP (2012) - £55.08/kWh, Zachariadis and Poullikkas (2012) - €118.06/kWh, Growitzch et al. (2013) - €102.93/kWh, Linares and Rey (2012) - €33.37/kWh

measured by our substitutability factor, is also an important driver. This may warrant further research for the construction industry and for other sectors that demonstrate high GVA based on low levels of consumption.

The impact of duration and notice

As expected, our primary research shows that WTA increases with the length of the supply interruption. In line with much of the literature, we observe that WTA per hour (i.e. the marginal WTA) reduces with duration. This applies for both domestic and non-domestic consumers.

Our survey has allowed us to assess the quantitative benefit of the provision of notice on VoLL for the first time[62]. In order to measure VoLA (i.e. VoLL given the provision of one-day of notice ahead of a disruption), we have defined a ‘notice factor’. For domestic consumers facing a two-hour supply interruption, we observe a notice factor of 55.5% meaning that VoLA is just over half the VoLL under these conditions.

By considering the combination of notice and duration, we have been able to quantify how the benefit of notice provision is influenced by the length of interruption that consumers will face following the notice period. We find that the ‘notice factor’ increases with length of interruption. Notice is less beneficial for consumers if they ultimately face a longer interruption.

Findings for non-domestic consumers show similar trends as for domestic consumers but differ in two ways. Firstly, while the WTA of non-domestic consumers also increases with length of the interruption, the level of disruption resulting from a short interruption appears to be much closer to that experienced under a longer interruption[63]. This suggests that, for non-domestic consumers, even a short electricity interruption would result in significant disruption to production processes. This may imply that these consumers are taking into account indirect costs such as damage to equipment and ‘hassle factors’.

Secondly, non-domestic consumers generally, and Industrial consumers in particular, do not benefit as much from the provision of notice compared to domestic consumers. The notice factor for non-domestic consumers for a two to four-hour supply interruption is 70.9% and this rises to 78.9% when Industrial consumers are considered independently. This suggests that while notice does benefit these consumers to some degree, much of their output is relatively fixed or dependent on electricity such that resource cannot be easily re-assigned to alternative productive activities even if notice is given. Consumers in the Services sector are slightly more able to make this shift, however.

[62] As far as we know – a limited set of previous literature considered notice provision but did not provide a quantitative impact on VoLL.

[63] We urge some caution in interpreting these results given that the design of the non-domestic survey differed from the domestic survey. While domestic consumers were able to enter any value for WTA, non-domestic consumers were limited to stating a percentage of their monthly bill.

Time-varying analysis

In order to consider how the value that consumers place on their electricity supply changes over time, we have defined a TSD, which is a function of the demand factor of consumers at any point in time.

Given data limitations[64], our analysis at a pan-EU level has depended on an assumption that the consumption profile is driven mainly by domestic consumers. This has allowed us to estimate the TSD based on time of day, day of the week and season for all MS across the EU. We have also conducted a case study of TSD for the UK, using consumption profile data sourced from ELEXON.

Our UK case study reinforces findings in relation to the seasonality of domestic TSD in the EU data. This suggests that our seasonal analysis of TSD for domestic consumers across the EU is relatively accurate. Using the EU data, we can therefore observe a pronounced seasonal differentiation for northern EU MS where we see higher TSD in the winter compared to the summer. Southern MS show the opposite, with higher TSD in summer, but with a less pronounced trend.

Our comparison also provides some support for the within-day profiles (day and night indicators) but suggests that the trend observed in the EU data (of a higher TSD in the day compared to the night) may in fact not be sufficiently pronounced.

Our comparison of the EU and UK data suggests that our assumption is not sufficiently accurate in relation to the day of the week however. While the EU ENTSO-E data for the UK suggests that weekday TSD is higher than at the weekend, our analysis of UK-specific ELEXON data suggests that TSD is generally higher on a Sunday than it is during the week. Responses of consumers to our domestic survey reinforce this. Nearly twice as many respondents state that they value electricity most at the weekends compared to on a weekday.

We suggest this as an area that would benefit from further research. Based on the provision of disaggregated consumption data[65] (e.g. for domestic, Services and Industrial consumers), TSD profiles could be developed for each of the consumer groups with greater accuracy.

7.1. Practical application of our findings

In Section 3 of this report, we presented several regulatory applications of VoLL. We consider that the findings from our research can be applied in a number of areas and present some of the main potential applications in Table 7.1 below:

[64] We have not been able to obtain disaggregated consumption profiles from ENTSO-E which would allow for more granular analysis of TSD by sector.

[65] It would be preferable to obtain this data at an EU level. However, given potential limitations, national level analysis may be carried out using data provided by TSOs.

Table 7.1: Potential applications of our VoLL research

Feature of our report	Applications	Explanation
Pan-EU VoLL estimates	All applications – particularly those which apply cross-border	We identified a number of applications that would benefit from a set of EU-wide VoLL estimates, established using a common methodology. For example, the quality of EU-wide network planning and CBAs could be enhanced by making use of these VoLL estimates where relevant.
VoLL estimates by sector	National network planning; interruptions incentives and compensation; informing demand-side-response programmes; informing the order of disconnection	In each of these applications, regulators, policy makers or network planners may benefit from being able to differentiate between consumer types and their estimated VoLL. For example, compensation programmes could be differentiated by consumer type, informed by disaggregated VoLL estimates. Where health and safety requirements allow, understanding relative VoLL could inform the order in which consumers are disconnected (perhaps alongside differentiated compensation payments) in the event of an interruption.
Impact of duration	System adequacy measures; procurement of balancing and back-up services; defining interruptions incentives and compensation	In each of these applications, decisions should be informed by the impact of a supply interruption should it occur. Understanding how duration of the interruption impacts on consumers may help to inform this.
Impact of notice	Network planning (at all levels); interruptions incentives and compensation; informing demand-side response programmes	Network planning may be informed by a balance between operational and investment solutions. Network owners and operators may have a range of options which include more frequent planned interruptions or less frequent but unplanned interruptions. Understanding the value that consumers place on the provision of notice ahead of an interruption can therefore help to inform planning as well as the incentives and compensation mechanisms that apply to planned relative to unplanned outages.
Time-varying analysis	Network planning; CBAs; design of capacity markets; procurement of balancing and back-up services; interruptions incentives and compensation	A number of policies and programmes include temporal consideration of the value placed on electricity. For example, network planners may time outages to coincide with periods in which they consider the extent of disruption to consumers to be lowest. An understanding of how the dependence of consumers on electricity varies over the day, the week, and the year, can allow the design of these mechanisms to be optimised.

Source: CEPA analysis

7.2. Proposed areas for further research

While this study has allowed us to develop valuable insights into consumer VoLL across the EU, we also acknowledge some specific limitations of our research. There are a number of areas in which more detailed analysis may add to the pan-EU VoLL estimates developed within this study. We summarise these areas in the table below:

Table 7.2: Recommended areas for further research

Area of further work	Description	Benefit
Substitutability and notice factors	More granular analysis of substitutability and notice factors, e.g. at national level and considering different types of consumer and different lengths of notice provision.	This would have three possible benefits: • Validating our analysis, given that we are the first to measure these attributes. • Refining assumptions at a more granular level (e.g. at a national/regional and sectoral level). • Exploring the relationship between the length of warning ahead of an interruption and VoLA.
Time-varying analysis	The methodology used for time-varying analysis within this report would benefit from disaggregated consumption data profiled over the year. This would allow for more granular analysis of TSD by sector than that carried out here. National authorities may wish to explore the provision of this data from their TSOs.	This would allow for more complete analysis of the TDS per consumption sector.
Outlier analysis	Where sectors have been identified which frequently provide high VoLL estimates (e.g. the 'Construction' sector), in depth analysis of VoLL may be valuable. This may include developing more granular understanding of the substitutability factors of these industry sectors.	This analysis may confirm that the high VoLL estimates experienced by these sectors are accurate. Alternatively, it may identify the discrepancy which repeatedly results in high VoLL estimates being established (e.g. based on the concept of the substitutability factor applied to these industries). A combination of these factors is also possible.
Analysis of disaggregated 'Services' sectors	A lack of consumption data for the sectors of the economy under the 'Services' label has prevented detailed analysis of the VoLLs of those industries included at the EU level. Where this data can be sourced, this would allow national	This would allow for more granular analysis of the VoLL of heterogeneous 'Services' sector consumers.

Area of further work	Description	Benefit
	authorities to build upon the analysis we have developed.	
Additional primary research	We have noted a number of limitations of the primary research that we carried out to support our analysis. More extensive primary research might explore the same issues to a greater degree.	This would allow for validation of the conclusions of our primary research while identifying any areas where the limitations identified have had an impact on findings.

Source: CEPA analysis

ANNEX A DETAILED LITERATURE REVIEW FINDINGS

A.1. Studies reviewed as part of the Task A literature review

Table A.1: Studies reviewed for Task A

Studies relevant for multiple or all EU MS
• Caves, Herriges and Windle (1992), 'The cost of electric power interruptions in the industrial sector: Estimates derived from interruptible service programs', Land Economics 68 (1), 180-198 • CEER (2010), 'Guidelines of Good practice on estimation of costs due to electricity interruptions and voltage disturbances', Ref: C10-EQS-41-01 • CEER (2015), 'CEER benchmarking report on the continuity of electricity supply', Ref: C14-EQS-62-03 • De Nooij, Koopmans and Bijvoet (2007), 'The value of supply security', Energy Econ. 29, 277-295 • ENTSO-E (2016), 'Draft Cost Benefit Analysis Methodology (CBA 2.0)' • European Union (SESAME) (2014), 'Assessment of security of electricity supply indicators in Europe' • Hoffman et al (for CEER) (2016), 'Good practice on estimation of costs due to electricity interruptions and voltage disturbances', SINTEF Energy Research • Schroder and Kuckshinrichs (2015), 'Value of lost load: An efficient economic indicator for power supply security? A literature review', Frontiers in Energy research, Volume 3, Article 55 • Shivakumar et al (2017), 'Valuing blackouts and lost leisure: Estimating electricity interruption costs for households across the European Union', Energy Research and Social Science (34), 39-48
Studies assessing VoLL or other reliability metrics in specific MS or other Countries
• Baarsma and Hop (2009), 'Pricing power outages in the Netherlands', Energy 34, 1378-1386 • Bertazzi, Fumagalli and Schiavo (2005), 'The use of customer outage cost surveys in policy decision making: The Italian experience in regulating quality of electricity supply', 18th International Conference and Exhibition on Electricity Distribution (CIRED), 1-5 • Bliem (2009), 'Economic valuation of electrical service reliability in Austria – a choice experiment approach', IHSK Working Paper • Bouri and El Assad (2016), 'The Lebanese electricity woes: An estimation of the economical costs of power interruptions', Energies (9), 583 • Carlsson and Martinsson (2008), 'Does it matter when a power outage occurs? – A choice experiment study on the willingness to pay to avoid power outages', Energy Economics (30), 1232-1245 • Carlsson, Martinsson and Akay (2009), The effect of power outages and cheap talk on willingness to pay to reduce outages', IZA Working Paper • Growitsch et al (2013), 'The costs of power interruptions in Germany – an assessment in the light of the Energiewende', Institute of Energy Economics at the University of Cologne (EWI) • Leahy and Tol (2010), 'An estimate of the value of lost load for Ireland', Energy Policy 39, 1514-1520 • Linares and Rey (2013), 'The costs of electricity interruptions in Spain: Are we sending the right signals?', Energy Policy 61, 751-760

- London Economics (2013), 'The value of lost load for electricity in Great Britain'
- Reckon LLP (2012), 'Desktop review and analysis of information on Value of Lost Load for RIIO-ED1 and associated work'
- Reichl, Schmidthaler and Schneider (2012), 'The value of supply security: the costs of power outages to Austrian households, firms and the public sector', Johannes Kepler University Linz
- Zachariadis and Poullikkas (2012), 'The costs of power outages: A case study from Cyprus', Energy Policy 51, 630-641

Other studies assessing different methodological approaches

- Hoch and James (2011), 'Valuing reliability in the national electricity market' for the Australian Energy Market Operator
- Lawton, Eto, Katz and Sullivan (2003), 'Characteristics and trends in a national study of consumer outage costs', CRRI 16th Annual Conference
- Shivakumar et al (2014), 'Estimating the socio-economic costs of electricity supply interruptions', Rapid Response Energy Brief (2) (Insight_E)
- Torriti (2017), 'Understanding the timing of energy demand through time use data: time of the day dependence of social practices', Energy Research and Social Science (25), 37-47
- V.S. Ajodhia (2006), 'Regulating Beyond Price: Integrated Price-Quality Regulation for Electricity Distribution Networks'
- Van der Welle and van der Zwaan (2007), 'An overview of selected studies on the value of lost load', Energy Research centre of the Netherlands (ECN)

A.2. Review of methodological approaches to estimating VoLL

A.2.1. Revealed preference approaches

Case studies

Case studies of previous supply outages can provide a 'natural experiment' from which to infer a monetary VoLL, using estimates of the resulting costs to the economy and consumers. In order to gather a sufficient sample of the members of an economy and to ensure robustness and validity of findings, data for long-lasting and large-area interruptions are needed. Herein lies a key limitation of the approach. While studying the impacts of an actual interruption can allow for rich analysis, the conditions required are extremely rare. Particularly in the EU where the level of supply security is generally very high, the opportunity for carrying out such studies is infrequent and limited to certain geographic areas. In addition, the fact that such events often occur without warning means that those who wish to study such events are not able to prepare in advance - to ensure collection of the required data, for example.

Zachariadis and Poullikkas (2012) provide an example of a case study being used to evaluate VoLL. They study the effects of an acute electricity interruption in Cyprus which suffered severe power shortages in the summer of 2011, following an explosion that destroyed 60% of its power generating capacity. This allowed the authors to estimate VoLL by economic sector, and to consider the hourly value of electricity by season and time of day. They employ two different economic methods (a production-function and demand-function method) to assess welfare losses and find that the estimated costs differ significantly.

Analysis of market behaviour

VoLL can also be established indirectly by analysing market behaviour. While there is no market for VoLL which allows for direct measurement, some groups of customers do invest in products and services that reinforce their level of security of supply to limit the potential impact of a supply disruption.

For example, studies may consider the level of investment in outside options such as back-up generation, or financial insurance taken out to cover the impacts of supply interruption. Such studies can be informative but are limited to those customers who have a sufficiently strong incentive to make such investments. This is generally limited to industrial, service or public service providers (e.g. hospitals) for whom electricity provision is a critical input. Such approaches currently provide very limited information on the VoLL of consumers who are less dependent on electricity or are less willing or able to invest in outside options. Changes in metering and small-scale generation/storage technologies may improve the ability for consumers to invest in outside options or express a price for security in future, increasing the potential for approaches based on analysis of market behaviour.

Caves, Herriges and Windle (1992) provide an example of estimates derived from market behaviour in the USA. They estimate outage costs for the industrial sector utilising data on interruptible service programs in which customers receive a discount on their bill for reducing power demand when requested (with some limitation on the frequency and length of demand reductions). They infer that the market that is created for reliability of delivery can be used to identify the expected costs of reduced reliability.

Production-function approach

Production-function approaches make use of macroeconomic data to infer the impacts of a hypothetical supply disruption on productive output (for non-domestic consumers) or on sacrificed value of leisure time (for domestic consumers). The approach is based on the consideration that electricity is an important input for consumers into the production and consumption of goods and services, such that production or leisure enjoyment is partially or fully reduced when there is a supply disruption. This allows for the impact on different sectors of the economy to be measured by using data on consumption, GVA and on wage rates[66].

While the production-function method requires several simplifying assumptions, it is a methodology which can be applied consistently from one region to another. Unlike case studies and studies of market behaviour, it is not dependent on the occurrence of a supply

[66] Wage rates serve as a proxy for value of leisure time given an assumed marginal propensity to balance working hours with enjoyment of leisure time.

interruption or on observed market behaviour to allow for estimates to be made. It can therefore be applied in any country for which data is available and allows estimates of VoLL for all customer groups, not only those who have engaged in a proxy market for supply security.

The production-function method has been applied in a number of studies and to many EU MS in the recent past[67]. Shivakumar (2017) used the method to estimate VoLL for domestic consumers across the EU.

A.2.2. Stated preference approaches

WTP and WTA

Under WTP and WTA approaches, consumers are surveyed and asked a series of questions which require them to state their preferences or expectations in relation to the hypothetical supply disruption scenarios under consideration. WTP requires the consumer to state how much they would be willing to pay to avoid a loss of electricity supply or to improve their level of supply security above a given baseline. Conversely, WTA requires consumers to state how much they would need to be paid to accept a loss of supply scenario.

While assumptions of rationality used within economic theory suggests that consumers should state the same value[68] for a given volume of reduction (or increase) in supply security, significant differences are consistently identified by practitioners when the two approaches are considered together. WTP studies generally result in significantly lower estimates than those derived using WTA. Explanations of this differential are often grounded in behavioural economics. Established behavioural biases such as the 'endowment effect', 'status quo bias' and 'loss aversion'[69], for example, may account for much of the difference in estimates identified.

Many different methodologies using WTP and WTA can be found in the literature. For instance, CEER (2010) propose triangulation using a number of different methods including WTA, WTP and direct worth. More recently, some have argued that requiring individuals to state their WTA for a disruption may provide a better estimate of 'true VoLL' than WTP (see for example London Economics (2013)[70]). Given the relatively low frequency of supply disruptions in the EU and the generally accepted consideration that close to uninterrupted access to electricity is usually seen as a right, consumers are likely to 'frame' a disruption as a

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[67] This includes the Republic of Ireland and Northern Ireland (Leahy and Tol (2010)), Germany (Growitsch, Malischek, Nick and Wetzel (2013)), Spain (linares and Rey (2012)), Cyprus (Zachariadis and Poullikkas (2012))[67], Portugal (Castro, Faias and Esteves (2016)), the Netherlands (de Nooij, Koopmans and Bijvoet (2007)) and Austria (Reichl, Schmidthaler and Schneider (2013)).

[68] Or at least very close. Theoretical differences may occur given the reduction or addition of supply security from a constant baseline which may lead to slightly different valuations given a non-linear set of preferences.

[69] See Kahneman, Knetsch and Thaler, 'Anomalies: The Endowment Effect, Loss Aversion and Status Quo Bias': https://www.princeton.edu/~kahneman/docs/Publications/Anomalies_DK_JLK_RHT_1991.pdf

[70] https://www.ofgem.gov.uk/ofgem-publications/82293/london-economics-value-lost-load-electricity-gbpdf

loss[71]. This is supported by the fact that many individuals submit 'protest' (zero or close to zero) WTP estimates for an improved level of service provision above an already high level.

Estimations based on such approaches exist for the UK (London Economics (2013)), Austria (Bliem (2009)), Sweden (Carlsson and Martinsson (2008)), Italy (Bertazzi, Fumagalli and Schiavo (2005)), and the Netherlands (Baarsma and Hop (2009)) amongst others.

Given challenges which may be present in converting WTP/WTA estimates into VoLL (i.e. difficulties in obtaining disaggregated and granular consumption data), the majority of these studies normalise estimates using units of time rather than converting estimates into VoLL. However, some studies (e.g. London Economics (2013)), utilise consumption profiles and make use of assumptions in order to develop VoLL estimates based on WTP/WTA studies.

Direct cost/worth

Direct worth approaches require consumers to focus on the monetary costs of supply interruption in order to evaluate WTP/WTA and/or VoLL based on the costs to the individual. Consumers are given a set of supply interruption scenarios and asked to think through the damage costs that they would incur under each. In some studies, consumers are also asked to categorise these damage costs. This is used in particular for non-domestic consumers for whom the different damage costs may result from different areas of the company's operations. This can allow for richer analysis of the drivers of damages which can help to inform policy or operational recommendations regarding ways to avoid certain drivers of damages.

Direct cost methods are sometimes used to complement WTA/WTP surveys. While in theory, damage costs should be captured in the responses of consumers to questions in relation to WTP and WTA, direct worth studies can help to make such damages more prescient in the mind of the consumer. Some argue that this allows for a more informed response.

A.2.3. Choice experiments, contingent valuation and the contingent ranking method

Where stated preference approaches are used (e.g. for WTP, WTA or direct worth studies), the two most common survey designs are contingent valuation (CV) and choice experiments (CE). Under CV, consumers are asked directly what they would be willing to pay or willing to accept to avoid/experience a certain supply disruption scenario. For example, questions may take the 'open form': *'What would you be willing to pay/accept to avoid/experience a supply disruption which left you without electricity for [N] minutes/hours at [TIME] on [DAY, MONTH]?'* Alternatively, the question may specify a certain amount of money and ask if the individual would be willing to pay/accept that amount for the scenario in question (a 'closed

[71] That is, consumers are far more likely to consider that they deserve payment (e.g. compensation) for accepting a loss of supply than they are to consider that they should have to pay to avoid such a loss.

form'). While the open form can be challenging for consumers to answer, the closed form may lead to anchoring in which the choice of options presented have a large impact on results.

CE differs from CV in that it presents two scenarios and asks consumers to state a preferred option. Under each scenario, the key attributes are changed in some way, and the individual is asked to choose which of the two scenarios they would prefer to experience. Each question in the CE therefore takes the form of two choice cards from which the individual must choose one (although they are usually provided with an option to state that they 'don't know'). A further option is the contingent ranking method (CRM). Under this approach, individuals are presented with several interruption scenarios with corresponding monetary value (e.g. compensation or cost) and must rank them in order of preference. By analysing the order of preferences, WTP/WTA estimates can be derived.

Both CV and CE approaches have been used in EU studies to estimate VoLL. While CV was perhaps more common in the past (see Bertazzi, Fumagalli and Schiavo (2005) for example), estimates have increasingly been made using CE approaches in more recent years.[72]

A number of studies suggest that the results of CE approaches can be more reliable where trade-offs between a number of different attributes need to be evaluated, as they allow for more realistic choices between alternatives. These choices can be used to construct preferences, rather than simply requiring individuals to express a WTP or WTA absent of a comparator (SINTEF, 2010). London Economics (2013) suggest that CE is more effective for testing VoLL under multi-attribute scenarios (e.g. comparing time, day of week, season and duration attributes). It is also suggested that in comparison to CV, CE may restrict the extent of 'strategic' responses, such as inflating WTA, or providing unrealistically low (or even zero) WTP with a lack of incentive to answer in line with actual preferences or behaviour.

However, CV can provide a more flexible and accurate estimate where a small number of attributes are being compared as there are no prior anchors for VoLL stated within the question or allowed responses. One limitation of CE is that responses, and hence VoLL estimates can be unduly influenced by the options or valuations that the practitioner decides to include in the survey.

It is also important to note that results from CE are derived using sophisticated econometric models. Therefore, a sufficient sample size is required to enable meaningful analysis. For example, the London Economics study of VoLL in Great Britain was based on 1,524 responses, and Baarsma and Hop's CE study (2009) was based on approximately 3,350 responses.

While meaningful statistical analysis using CV approaches also benefits from relatively large sample sizes, the approach is more flexible in allowing for qualitative and quantitate analysis and the consideration of statistical significance.

[72] For example, Baarsma and Hop (2009), Bliem (2009) and London Economics (2013).

A.3. Summary of market segmentation of non-domestic consumers identified from the literature review

Table A.2: Summary of non-domestic consumer segmentation in a selection of studies across Europe

<table>
<tr><th colspan="2"></th><th>London Economics (2013)</th><th>Leahy and Tol (2010)</th><th>Growitsch et al. (2013)</th><th>Linares and Rey (2012)</th><th>Bertazzi, Fumagalli and Schiavo (2005)</th><th>Zachariadis and Poulikkas (2012)</th></tr>
<tr><td colspan="2">Location</td><td>Great Britain</td><td>Republic of Ireland and Northern Ireland</td><td>Germany</td><td>Spain</td><td>Italy</td><td>Cyprus</td></tr>
<tr><td colspan="2">Methodology for I&C consumers</td><td>Production-function (excluding SMEs)</td><td>Production-function</td><td>Production-function</td><td>Production-function</td><td>Contingent valuation interviews</td><td>Production-function</td></tr>
<tr><td colspan="2">Number of I&C sub-sectors</td><td>27</td><td>2</td><td>15</td><td>14</td><td>3</td><td>14</td></tr>
<tr><td rowspan="18">Sub-sectors</td><td>Industry</td><td></td><td>☑</td><td></td><td></td><td>☑</td><td></td></tr>
<tr><td>Services</td><td></td><td>☑</td><td>☑</td><td>☑</td><td>☑</td><td>☑</td></tr>
<tr><td>Commerce</td><td></td><td></td><td></td><td></td><td>☑</td><td>☑</td></tr>
<tr><td>Government/ public admin.</td><td></td><td></td><td></td><td>☑</td><td></td><td>☑</td></tr>
<tr><td>Other mining and quarrying</td><td>☑</td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Food products</td><td>☑</td><td></td><td rowspan="3">☑</td><td rowspan="2">☑</td><td></td><td></td></tr>
<tr><td>Beverages</td><td>☑</td><td></td><td></td><td></td></tr>
<tr><td>Tobacco products</td><td>☑</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Textiles</td><td>☑</td><td></td><td></td><td>☑</td><td></td><td></td></tr>
<tr><td>Wearing apparel</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Leather and related products</td><td>☑</td><td></td><td>☑</td><td></td><td></td><td></td></tr>
<tr><td>Wood and wood products</td><td>☑</td><td></td><td>☑</td><td>☑</td><td></td><td></td></tr>
<tr><td>Paper and paper products</td><td>☑</td><td></td><td rowspan="2">☑</td><td>☑</td><td></td><td></td></tr>
<tr><td>Printing and recorded media</td><td>☑</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Coke and refined petroleum</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Chemicals</td><td>☑</td><td></td><td>☑</td><td>☑</td><td></td><td></td></tr>
<tr><td>Pharmaceuticals</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Rubber and plastics</td><td>☑</td><td></td><td>☑</td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><th></th><th></th><th>London Economics (2013)</th><th>Leahy and Tol (2010)</th><th>Growitsch et al. (2013)</th><th>Linares and Rey (2012)</th><th>Bertazzi, Fumagalli and Schiavo (2005)</th><th>Zachariadis and Poulikkas (2012)</th></tr>
<tr><td rowspan="5"></td><td>Other non-metallic minerals</td><td>☑</td><td></td><td>☑</td><td>☑</td><td></td><td></td></tr>
<tr><td>Basic metals</td><td>☑</td><td></td><td rowspan="2">☑</td><td rowspan="2">☑</td><td></td><td></td></tr>
<tr><td>Fabricated metals</td><td>☑</td><td></td><td></td><td></td></tr>
<tr><td>Computers and electronics</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Electrical equipment</td><td>☑</td><td></td><td>☑</td><td></td><td></td><td></td></tr>
<tr><td rowspan="17">Sub-sectors</td><td>Machinery</td><td>☑</td><td></td><td>☑</td><td>☑</td><td></td><td></td></tr>
<tr><td>Motor vehicles</td><td>☑</td><td></td><td rowspan="2">☑</td><td rowspan="2">☑</td><td></td><td></td></tr>
<tr><td>Other transport</td><td>☑</td><td></td><td></td><td></td></tr>
<tr><td>Furniture</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other manufacturing</td><td>☑</td><td></td><td>☑</td><td></td><td></td><td>☑</td></tr>
<tr><td>Water collection</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Waste collection</td><td>☑</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Civil engineering/ construction</td><td>☑</td><td></td><td>☑</td><td>☑</td><td></td><td>☑</td></tr>
<tr><td>Agriculture and fishing</td><td></td><td></td><td>☑</td><td>☑</td><td></td><td>☑</td></tr>
<tr><td>Manufacturing of transport</td><td></td><td></td><td></td><td>☑</td><td></td><td></td></tr>
<tr><td>Cement industry</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Gas and water supply</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Health</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Trade</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Hotels and restaurants</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Education</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td>☑</td></tr>
</table>

Source: CEPA analysis

ANNEX B EXAMPLES OF APPLICATIONS OF VOLL

Different MS have used or investigated application of VoLL in a number of areas of policy, regulation or market design. The table below sets out examples of a number of applications:

Table B.1: Examples of applications of VoLL in the EU

Application	Type	Description	Examples of use
Cost-benefit analyses (CBA) for network investment	Evaluation	Network reinforcement involves a trade-off between the up-front capital cost requirements and the additional security of supply benefit. VoLL can be used to inform the monetary benefit of additional supply security to strengthen the CBA.	European Commission's pan-European CBA for optimal expansion of electricity transmission system.
Demand side response alternatives to network reinforcement	Evaluation	Increasing opportunities for more flexible use of the electricity networks allows network companies to consider alternatives to network reinforcement which include demand side response. For example, they may agree interruptible connections with connected customers. In order to inform the CBA and potentially to define the terms of an interruptible connection agreement, VoLL may be used.	UK Power Network's 'I&C Demand Response for Outage Management as an Alternative to Network Reinforcement'[73]
System adequacy assessment	Evaluation	Some MS require ongoing monitoring of the level of security of supply and the transparency of indicators in comparison to thresholds above or below which supply security measures	In Germany, monitoring of system adequacy is required within the Energy Economics Act. In the UK, the Government and NRA jointly produce an annual report on electricity supply security[74].

[73] https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-(LCL)/Project-Documents/LCL%20Learning%20Report%20-%20A4%20-%20Industrial%20and%20Commercial%20Demand%20Side%20Response%20for%20outage%20management%20and%20as%20an%20alternative%20to%20network%20reinforcement.pdf

[74] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/663894/hc536-statutory-security-of-supply-report-2017.pdf

		may be applied or developed.	
Setting harmonised maximum and minimum clearing prices	Wholesale market design and price signals	Nominated Electricity Market Operators are required to take into account estimates of VoLL in setting the intraday and day-ahead clearing prices within a respective bidding zone.	The Capacity Allocation and Congestion Management framework guideline[75].
Design of MS-level capacity mechanisms (including capacity markets and strategic reserves)	Direct procurement of security of supply	VoLL could be combined with modelling of the LoLP to define the volume and price relationships within the design of regional capacity markets.	Could be applied in multiple MS within the internal market where a capacity mechanism is planned or present – e.g. the capacity markets within Great Britain and Ireland or the strategic reserve planned for introduction in Germany in 2019.
Wholesale market scarcity price signals	Wholesale market design and price signals	In order to ensure that market participants face appropriate signals to ensure they are balancing their positions, actions which are needed to avoid outages in the event of an energy imbalance can be priced relative to VoLL. This places an incentive on participants to avoid an imbalance position.	Imbalance pricing in Great Britain following Ofgem's electricity balancing significant code review. Article 9 of the proposed recast of the Electricity Regulation allows for a maximum wholesale electricity price, only if it is set at VoLL.
Defining interruptions incentives and compensation to customers in the event of disconnection	Regulatory incentives and compensation	VoLL can be used as an input to incentives on network companies for supply continuity. Where disconnections do occur, VoLL can be used as an administrative price for compensating consumers for their lost supply. This can be applied to supply disruptions which take place for reasons of shortage of supply or due to network	Performance based incentives for supply continuity in Germany, Italy, the UK and the Netherlands. Considered for standards of reliability in electricity network regulation in Great Britain. Not yet applied for levels of compensation which are still set administratively.

[75] http://www.acer.europa.eu/official_documents/acts_of_the_agency/framework_guidelines/pages/fg-on-capacity-allocation-and-.aspx

		outages (whether planned or unplanned).	
Informing the order of disconnection in the event of a supply disruption	Wholesale market design and price signals	Where supply disruptions occur for reasons of supply-demand imbalance, system operators need to define the hierarchy in which they take actions to disconnect demand. Accurate VoLL metrics could better inform the priority order of customer disconnection to be reflective of the value placed on supply.	Not clear whether this is formally in place in any jurisdiction. Other factors such as technical capabilities and ease of re-connection will also be influencing factors.
Driving optimal procurement levels for balancing and back-up services (e.g. black start)	Direct procurement of security of supply	The standards of supply security that system operators work to are often led by an (implicit or explicit) requirement to avoid customer disconnections at close to any cost. Procurement of reserve services and back-up services such as Black Start could be better informed by justified VoLL figures.	Does not appear to be applied in any jurisdiction within the internal market.

Source: CEPA Analysis

In Section 3.2, we provided our view on the extent to which consistent methodologies for calculating VoLL are beneficial EU-wide, regional or national level in relation to a number of practical applications. In the table below, we provide further detail on our rationale.

Table B.2: Rationale for application of VoLL estimate

Regulatory application	EU wide/Regional/ National VoLL estimate	Rationale
EU network planning	EU-wide	Optimal cross-border network planning and evaluation requires VoLL estimates which have been developed using a common methodology.
EU-wide cost-benefit analyses	EU-wide	Where EU policy or initiatives may be expected to have an impact on security of supply of MS, use of VoLL estimates established using a common methodology should allow for better informed cost-benefit analyses.

Regulatory application	EU wide/Regional/ National VoLL estimate	Rationale
System adequacy assessments	EU wide	Interactions between national levels of supply adequacy need to be considered. While each MS may apply different system adequacy thresholds depending upon specific contexts, standardisation of the methodology used to calculate these thresholds, including using a common methodology for the calculation of VoLL would be beneficial.
Setting harmonised maximum and minimum clearing prices	Regional/EU-wide	An estimation of the VoLL should feed into proposals for harmonised maximum and minimum clearing prices. Given that this requirement applies to bidding zones that participate in day-ahead coupling, we would recommend that the VoLL estimates used are derived using a consistent methodology at least at the regional level. However, as market coupling expands across Europe, interactions between regions may drive a preference for estimates using a common EU-wide methodology.
Wholesale market scarcity price signals	Regional	While we would expect that the NRAs of each MS would wish to develop their own regulatory approaches to defining wholesale scarcity pricing, the interactions between scarcity prices and the implications for cross border electricity flows should be taken into account in the context of a harmonised EU market. We therefore consider that the methodologies used to define the VoLL that is used within such calculations should be consistent at a regional level (for example within market coupling regions) at the least.
Driving optimal procurement levels for balancing and back-up services (e.g. black start)	Regional	Similar to wholesale market scarcity signals, while it is for the respective NRAs and system operators to determine their own procurement strategies, integration of electricity balancing markets is an additional objective of EU electricity policy (see the Trans European Replacement Reserves Exchange project[76]). Therefore, where VoLL is used as an input into balancing services procurement strategies, the existence of objectives for cross-border balancing markets would suggest that this should be established at the regional level at least.

[76] https://www.emissions-euets.com/internal-electricity-market-glossary/1041-terre-trans-european-replacement-reserves-exchange

Regulatory application	EU wide/Regional/ National VoLL estimate	Rationale
Design of MS-level capacity markets	National/ Regional	It is argued that capacity markets can be more optimal and efficient where they can make use of cross-border capacity – for example some capacity markets allow interconnectors to enter into the auctions. However, inconsistencies in the design of national auctions can limit the extent of this benefit. Where VoLL is introduced into the design of capacity markets (for example to inform the market price cap), a regional VoLL may allow for the potential benefits of cross-border cooperation and additional efficiencies over time.
National network planning	National (but may be preferable to use regional/EU-wide estimates in practice)	While EU and regional network planning requires use of VoLL which has been defined using a consistent cross-border methodology, national planning may be performed using nationally derived VoLL estimates. However, potential cross-border interactions should be carefully considered even where not immediately apparent. In addition, applying different VoLLs to national and cross-border planning may raise inconsistencies. This should also be considered in the context of ENTSO-E's guidelines and its stated intentions for system development to be assessed beyond national boundaries. It may therefore be preferable to encourage the use of the EU-wide estimates derived under this study.
National cost benefit analyses	National (but may be preferable to use regional/EU-wide estimates in practice)	Where security of supply effects are largely internal within a MS, a national cost benefit analysis may make use of national VoLL estimates. However, this may introduce inconsistencies between decisions made at national and EU level. Therefore, use of EU-wide VoLL estimates may be preferable.
Defining interruptions incentives and compensation to customers in the event of disconnection	National	It is for the authorities of the MS to determine performance-based incentives and compensation procedures in the event of a supply disconnection. Many MS already have such arrangements in place. Particularly when applied at distribution level, national VoLL estimates may be preferred. Where such arrangements are in place at transmission level, interactions between continuity incentives and infrastructure planning may need to be considered.

Regulatory application	EU wide/Regional/ National VoLL estimate	Rationale
Distribution network planning and considering operational alternatives (e.g. demand side response)	National	Given that cross-border interactions are far less likely at distribution level, nationally derived VoLL estimates may be preferred, particularly where these align with existing performance incentives and/or compensation arrangements. By extension, the approach used for considering operational alternatives to investment such as DSR may also incorporate national VoLL.
Informing the order of disconnection in the event of a supply disruption	National	In the event that disconnection of electricity consumers is required, and an order of disconnection needs to be determined, it will be for national policymakers and system operators to determine the order of such disconnection. It is also likely that additional technical and political considerations will be relevant for such decisions. It may therefore be more suitable for the respective authorities of individual MS to determine where and how VoLL estimates feed into such calculations. However, we note that where interconnectors may be disconnected, this may clearly have cross-border implications. In this regard, it may be more optimal for authorities to take account of EU-wide VoLL estimates where disconnection of interconnectors is a realistic possibility.

Source: CEPA Analysis

ANNEX C DETAILED VOLL METHODOLOGY

We summarised our methodology for calculating VoLL in Section 4 of this report. Here, we provide further detail on some of the key steps.

C.1. Domestic VoLL

Using data on time use and wages, assumptions about the substitutability factor and the relative value placed on leisure time by those who are not employed, we calculated the total value of leisure at MS level using the following equation.

Equation 1:

$$Leisure\ value_{MS} = hours\ spent\ on\ leisure\ activities_{MS} \times hourly\ wage_{MS} \times substitutability\ factor_{MS} \times (number\ of\ employed\ people_{MS} + nonemployed\ coefficient_{MS} \times number\ of\ nonemployed\ people_{MS})$$

The following subsections set out the data and assumptions used, including data sources and areas where we have developed or refined assumptions using our primary research.

Calculate time spent on leisure activities

To calculate the average time spent on leisure activities for any given day, we needed information for each MS on:

- Hours spent on personal care each day (hours / day)
- Hours spent at work each day (hours / working day)
- Number of working days in a year

We then calculated the average hours spent on leisure per day for each MS using:

Equation 2:

$$\begin{aligned} &Average\ hours\ spent\ on\ leisure\ per\ day_{MS} \\ &\quad = (hours\ in\ a\ day - personal\ care\ hours\ per\ day \\ &\quad - average\ working\ hours\ per\ working\ day_{MS})\ x\ \frac{working\ days_{MS}}{total\ days\ in\ a\ year} \\ &\quad + \ (hours\ in\ a\ day - personal\ care\ hours\ per\ day)\ x\ \frac{non - working\ days_{MS}}{total\ days\ in\ a\ year} \end{aligned}$$

The data sources and assumptions used to determine the terms within Equation 2 are discussed below:

- **Personal care hours per day** - previous literature has estimated that 11 hours of the day is spent on sleeping and personal care (e.g. Growitsch et al (2013)) with the remainder shared between work and leisure activity. Data on time use is also available for 14 EU countries from Eurostat, which demonstrated that variability from one country to the next is low with average time spent on personal care of 11 hours and

19 minutes[77]. As a result, we considered that the previously applied assumption of 11 hours is justified for time spent on sleeping and personal care.

- **Working days** – available from the European Commission for each MS[78].
- **Average working hours per working day** – data is available from Eurostat on average usual weekly hours worked[79]. We have multiplied this data by 52 to obtain average yearly hours worked for each MS, and then divided this figure by the number of working days in a year to obtain average hours worked per working day.

Calculating the value placed on leisure activity by employed individuals

Our approach towards assessing the VoLL of domestic consumers has been based on the assumption that the VoLL of households is largely driven by the interruption of leisure[80].

One limitation of this assumption is that it does not take account of the indirect costs of a disruption. For electricity interruptions of short duration (minutes or a small number of hours), this assumption is considered acceptable. In the case of electricity interruptions of up to four hours in length, it is unlikely that refrigerated items would be damaged[81]. In addition, as battery-based electronics (laptops, tablets and mobiles) become increasingly prevalent, electronics related damages are likely to decrease. For disruptions of longer duration, VoLL estimates based on the production-function approach may represent an under-estimate. However, our consideration of the relative impact of the duration of the interruption (comparing interruptions from 20 minutes to two days in length) is informed by our primary research. As respondents were able to express a WTA in response to outages of differing durations, this should capture indirect costs of outages of longer duration to some degree.

We further assume that, at the margin, individuals are indifferent between an additional hour of labour and an additional hour of leisure. This assumption is based on labour economic theory which proposes that households gain utility from consuming goods and time spent on leisure activities, and that the money required to purchase these goods is obtained through working which represents time that cannot be spent on leisure activities.[82] As a result, there

[77] Eurostat, source I.D. [tus_00age].
[78] European Commission https://ec.europa.eu/eurostat/cros/content/euro-area-and-eu-working-days-build-calendar-adjustment-regressor_en
[79] Eurostat, source I.D. [lfsa_ewhun2].
[80] It is important to note that we define 'leisure' in the broadest sense of the term. Our definition is not limited to entertainment activities such as watching television, playing games, etc. It relates to all time which is not spent working, sleeping, eating or on personal care (working is not included as this is captured within our non-domestic VoLL estimates through contribution to GVA. We have followed previous literature in not including sleeping, eating or personal care within our definition of leisure based on the assumption that interruption of electricity does not affect these activities to a significant degree. Particularly in the case of eating and personal care, this point could be argued but is considered sufficiently accurate for the purposes of evaluating VoLL.
[81] For example, UK food safety standards suggest that a refrigerator will keep cold for four hours without power if left closed: https://www.foodsafety.gov/blog/poweroutage.html
[82] Becker, 1965. A theory of the allocation of time, Econ. J. 75 (September (299)) 493 – 517.

is an optimal allocation of time between work and leisure where an individual or household is indifferent between an additional hour of work and an additional hour of labour. Based on this assumption, we can impose the assumption that an additional hour of leisure has the same value as the income generated from an additional hour of work (i.e. average net hourly wage)[83].

Based on data availability, the average net hourly wage for each MS is estimated as follows:

Equation 3:

$$Average\ net\ hourly\ wage_{MS} = \frac{Annual\ average\ net\ earnings_{MS}}{Working\ days_{MS}}\ x\ \frac{1}{average\ working\ hours\ per\ working\ day_{MS}}$$

Where annual average net earnings data for each MS is sourced from Eurostat[84]. We have used average annual net earnings for a single earner with no children, which we consider is the most appropriate assumption given the data available.

Average employed leisure value per day is then calculated as:

Equation 4:

$$Average\ employed\ leisure\ value\ per\ day_{MS} = Average\ hours\ spent\ on\ leisure\ per\ day_{MS}\ x\ Average\ net\ hourly\ wage_{MS}$$

Develop assumptions regarding the 'substitutability factor'

Not all of an individual's leisure time is dependent on electricity. For example, outdoor leisure activities such as sports or park-based leisure activities do not require electricity. In order to identify VoLL, we have determined the proportion of the value of leisure activity that is dependent on electricity. We define this as the 'substitutability factor' with a value of between 0 and 1. A high substitutability factor (i.e. close to 1) indicates that a large proportion of leisure activity is dependent on electricity.

Previous literature has consistently applied a substitutability factor of 0.5[85]. However, we identified this as a key assumption to explore further through our primary research. In order to achieve this, we included a question in our survey which related to the dependence of consumers on electricity for enjoyment of their leisure time.

[83] We also note that this methodology implicitly assumes that it is the marginal unit of leisure which is interrupted by a supply disruption. While it may be preferable to take the average unit of leisure as the unit of lost leisure, unlike the marginal unit this cannot be estimated. The marginal unit is therefore used as an approximation of the average unit.

[84] Eurostat, source I.D. [earn_nt_net]

[85] For example, see Leahy and Tol (2010) and Shivakumar et al (2017)

Develop assumptions about the value placed on leisure time by those who are not employed

For those who are not employed (whether unemployed, pensioners, those with a disability that prevents employment, in education, etc.), the value of leisure time can no longer be equated to hourly wages, because this method may lead to an overestimation of VoLL. Therefore, we have made an assumption regarding the value placed on leisure by those not employed relative to the value of leisure by the employed. We label this the 'non-employed factor'.

The approach previously applied in the literature has been to use a non-employed factor of 0.5, e.g. recently applied by Shivakumar et al (2017). The number of non-employed individuals that responded to our survey was not sufficient to refine this assumption. We therefore apply a non-employed factor as our base-case assumption but have carried out sensitivities to measure the impact of varying this assumption between 0.25 and 0.75. We present the findings of this sensitivity analysis in ANNEX I.

Calculate annual average household VoLL

After combining the above data and assumptions to calculate the total annual leisure value, we have calculated the VoLL of households by dividing this by the annual total household electricity consumption, using the following equation:

Equation 5:

$$VoLL_{MS} = \frac{LV_{MS}}{ELC_{MS}}$$

where LV_{MS} is the leisure value of each MS, and ELC_{MS} is the annual domestic electricity consumption of each MS.

The relationship between outage duration and VoLL

We have used our primary research to explore the relationship between duration of a supply interruption and WTA for that interruption. This has allowed us to develop analysis of the relative difference in stated WTA given three supply disruption scenarios. We asked respondents to state a WTA in relation to an outage of 20 minutes, 2 hours and 48 hours duration.

C.2. Non-Domestic VoLL

We used the production-function approach to relate electricity consumption to the actual value of firm output (measured using GVA) for each of our disaggregated non-domestic sectors using the following equation.

Equation 6:

$$VoLL_{business} = \frac{GVA_{business}}{ELC_{business,MS,A}}$$

where GVA is the annual amount in €millions of the value added generated by the relevant sector, and $ELC_{business,MS}$ is the annual electricity consumption by the same sector.

As with domestic consumers, this will provide us with the average VoLL for each of our consumer sectors.

Substitutability factor and VoLA

As with domestic consumers, we have been able to analyse the 'substitutability factor' and 'notice factor' of non-domestic consumers using our primary research. In terms of non-domestic consumers, this represents the extent to which electricity is critical for productive output, and the extent to which this changes given one day of notice ahead of a disruption, respectively.

When the substitutability factor is included, the equation for VoLL for non-domestic consumers becomes:

Equation 7:

$$VoLL_{business} = substitutability\ factor_{business} \times \frac{gross\ value\ added_{business}}{ELC_{business,MS}}$$

C.3. VoLA

For both domestic and non-domestic consumers, we have also estimated VoLA by applying a 'notice factor' revealed by consumers through responses to our primary research. When combined with the substitutability factor, the equations for VoLA becomes:

Equation 8:

$$VoLA_{MS} = notice\ factor \times \frac{LV_{MS}}{ELC_{MS}}$$

Equation 9:

$$VoLA_{business} = substitutability\ factor_{business} \times notice\ factor_{business} \times \frac{gross\ value\ added_{business}}{ELC_{business,MS}}$$

C.4. TSD analysis

In order to consider the level of dependence of electricity consumers over time, we utilise the demand factor. This measures the ratio of actual consumption at a point in time to the average demand over the course of the year:

Equation 10:

$$Demand\ factor = \frac{Time\ specific\ electricity\ demand_{MS,t}}{Average\ electricity\ demand_{MS,A}} = \frac{ELC_{MS,t}}{ELC_{MS,A}}$$

Using this demand factor, and where granular profiled consumption data exists, we can evaluate the TSD for domestic consumers and for each of our non-domestic consumer groups:

Equation 11:

$$TSD_{domestic} = VoLL_{domestic} \times Demand\ factor_{domestic}$$

Equation 12:

$$TSD_{business} = VoLL_{business} \times Demand\ factor_{business}$$

In order to explore the TSD for each consumer sector on a time-varying basis, we would need to make use of data on consumption for each of our disaggregated consumer sectors. As we have not been able to source this data at EU-level, we have made the simplifying assumption that the consumption profile and GVA of non-domestic consumers is fixed over the course of the year. This has allowed us to evaluate the TSD of domestic consumers by assuming that the profile of consumption over the year (and hence the demand factor) is driven by domestic consumers.

To test this assumption, we have produced a UK case study using eight representative load profiles constructed by ELEXON. These load profiles cover different types of electricity consumers (domestic, non-domestic, and non-domestic ‘maximum demand’ customers). While the match against our Services and Industry sectors is important, it is considered to be sufficiently aligned to allow for meaningful analysis. We have also cross-checked this analysis with the results of primary research in which we asked consumers to indicate at which times of the day, week and year consumption was most important for leisure or productive output.

C.5. Data sources, assumptions and limitations

In this section, we summarise the publicly available data sources that we have used to estimate VoLL in addition to key data limitations and assumptions.

C.5.1. Data sources and assumptions

Our choice of data was informed by our literature review and an in-depth review of available data sources, considering completeness and quality[86]. Based on this review, we identified the most recent, complete and high-quality set of data to be for the year 2015. Data for more recent years was found to be less complete, such that gaps in the data would have impacted on the quality and consistency of our analysis.

The majority of data that we used to calculate VoLL was available from Eurostat, the European Commission and/or ENTSO-E. In certain cases, we supplemented our EU-wide data with analysis of national data in order to provide insight into certain objectives of the study.

A summary of the data sources used for this study is presented in the tables below. Table C.1 outlines the sources used to estimate VoLL for domestic consumers, and Table C.2 summarises sources used to estimate VoLL for non-domestic consumers.

Table C.1: Data sources and assumptions for the estimation of domestic VoLL

Variable	Source	Units	Comments
Hours worked	Eurostat [lfsa_ewhun2]	Average usual weekly hours for employed individual[87]	• Used to derive time spent on leisure activities per day.
Hours spent sleeping and on personal care per day	CEPA literature review; Eurostat [tus_00age]	Hours per day	• Assumed 11 hours of each day is spent on sleeping and personal care based on our literature review.[88]
Substitutability factor	CEPA primary research	%	• We used our primary research to explore the substitutability factor. We set out our findings in Section 5.
Population employed/ not employed	Eurostat [lfsa_pganws]	Average annual figures in thousands	• The non-employed include all those who are not working. • Calculated by subtracting the number of employed people from the overall population.
Annual domestic electricity consumption	Eurostat [nrg_105a]	Gigawatt-hour (GWh)	• Available from Eurostat.

[86] We estimated annual average VoLL for the EU28 Member States. We did not estimate VoLL for Iceland, Liechtenstein, Norway and Switzerland - who are part of the European Free Trade Association (EFTA) but not part of the European Union.

[87] Usual hours exclude hours not worked because of public holidays, annual paid leave, own illness, injury and temporary disability, maternity leave, parental leave, schooling or training, slack work for technical or economic reasons, strike or labour dispute, bad weather, compensation leave and other reasons.

[88] Analysis of Eurostat time use data justifies this assumption.

Variable	Source	Units	Comments
Hourly domestic electricity consumption	ENTSO-E[89]; ELEXON settlement data[90]	Megawatts (MW)	• Hourly load data is available from ENTSO-E for total load.[91] • For our primary analysis of TSD, we make the assumption that the profile of electricity consumption over time is driven primarily by domestic consumers. • We also used ELEXON representative profile classes to develop a case study of hourly consumption for the case of Great Britain by sector.
Non-employed value of leisure time	Literature review	%	• Our baseline assumption follows the literature, applying a value of leisure of non-employed people equal to 50% of employed people.[92] • We also conduct sensitivity analysis to assess the impact of the 50% assumption on results.
Notice factor	Regulatory precedent	%	• We used our primary research to explore the substitutability factor. We set out our findings in Section 6.

[89] https://www.entsoe.eu/data/data-portal/consumption/Pages/default.aspx
[90] https://www.elexon.co.uk/operations-settlement/profiling/
[91] Total load is defined as a load equal to generation and any imports deducting any exports and power used for energy storage.
[92] This may be the case due to lower levels of income for these groups as well as the fact that these individuals may have a greater level of leisure time, leading to a lower marginal valuation of this time. E.g. Shivakumar (2017)

Table C.2: Data sources and assumptions for the estimation of non-domestic VoLL

Variable	Source	Units	CEPA Comments
GVA by use/ industry sector	Eurostat [nama_10_a64]	Current prices, million euro	• Eurostat provides GVA data by industry sector at the level of disaggregation required for the majority of MS. We outline any gaps in the data below.
Annual electricity consumption by use	Eurostat [nrg_105a]	Gigawatt-hour (GWh)	• Final energy consumption is broken down into 13 industries, four transport uses and five other sectors.
Hourly electricity consumption data by use/ industry	ELEXON settlement data[93]	KWh	• We used ELEXON representative profile classes to develop a case study of hourly consumption for the case of Great Britain, disaggregated by sector.
Substitutability factor	Primary research	%	• We used our primary research to explore the substitutability and notice factor. We set out our findings in Section 6.2.
Notice factor			

C.5.2. Data limitations and impacts on methodology

We have identified three main limitations with the data:

1. A mismatch between GVA and electricity consumption data.
2. Missing data points for specific variables in certain MS.
3. Lack of hourly load data at a disaggregated consumer level.

While these limitations have not prevented us from developing and exploring VoLL estimates across a range of consumption sectors, they provide insight into areas which may benefit from further research following this study. We explore each of these limitations in turn.

Mismatch between GVA and electricity consumption data

GVA data by industry/sector is available from Eurostat at a higher level of disaggregation than electricity consumption data by industry. As a result, we have mapped GVA data onto electricity consumption data using definitions provided by Eurostat's RAMON database. Our market segmentation is outlined in Section 5 and our mapping of GVA to consumption is presented in ANNEX D.

[93] https://www.elexon.co.uk/operations-settlement/profiling/

Missing data points for specific variables

We observed a limited number of instances where particular data points are missing from the Eurostat data for certain MS. ANNEX E lists the missing data points and sets out how we have managed these gaps in the data. In the majority of cases, we have filled gaps using data from the national statistical offices of the respective countries and / or applied the EU28 average (weighted where applicable) to obtain an estimate for that particular observation. The latter approach was applied when national statistical offices were contacted but were unable to provide the required data.

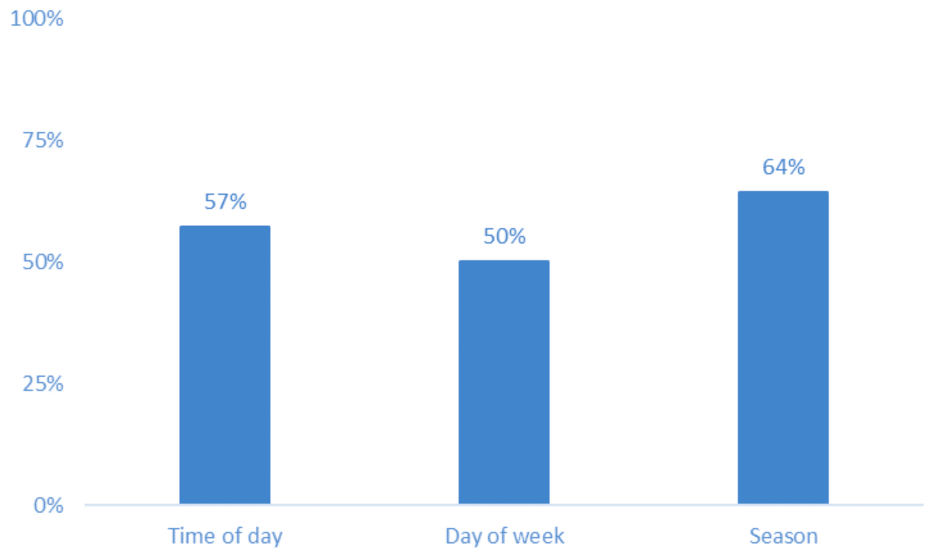
Lack of hourly load data at a disaggregated level

ENTSO-E only provide hourly load data for total load at an aggregated MS level (i.e. not disaggregated to a sectoral level). While this has not impacted on the disaggregation and the accuracy of *annual* VoLL estimates, it has required the use of assumptions in order to inform our analysis of TSD for all consumer sectors.

The assumption used for our headline estimates of TSD is that the profile of electricity consumption for the MS as a whole is primarily driven by domestic consumers. In turn, we assume that non-domestic consumers have a flatter demand profile over the day, week and year. While imperfect, the suitability of this assumption is justified by a number of sources. For example, Leahy and Tol (2010) provide one of the few examples of considering the time-varying nature of VoLL. They identify a significantly flatter VoLL profile for non-domestic (particularly Industrial consumers) in comparison to domestic consumers.

Our primary research also suggests that this may be a reasonable simplifying assumption. In response to questions regarding when electricity is most important to productive output, around 65% specify 'no difference' between summer and winter, 50% specify 'no difference' between a weekday and the weekend, and 57% specify 'no difference' between different times of the day.

Figure C.1: Proportion of non-domestic respondent stating given timing makes 'no difference' to an outage



Source: CEPA Analysis

While we consider this to be a reasonable assumption for the consideration of our headline TSD analysis, we have explored TSD for different types of consumer through a case study of Great Britain. Using ELEXON settlement load profiles[94], we have developed consumption profiles for three classes of consumers – domestic, services and industrial consumers[95]. Our results are presented in Section 6.3.2 of this report.

[94] https://www.elexon.co.uk/operations-settlement/profiling/

[95] We use Profile Class 1 'Domestic Unrestricted Customers' to profile domestic consumers, Profile Class 3 'Non-Domestic Unrestricted Customers' to profile Services customers and a consumption weighted average of Profile Classes 5-8 'Non-Domestic Maximum Demand Customers' to profile non-domestic consumers.

ANNEX D MAPPING OF SECTORS BETWEEN ELECTRICITY CONSUMPTION AND GVA

Our calculation of VoLL for non-domestic consumers is based on the GVA and consumption of the relevant consumer sector. Based on the data available at EU level, we have applied the matching of data and identified those sectors set out in the table below.

Table D.1: Mapping of sectors between electricity consumption and GVA

Match No.	Electricity consumption label	GVA label
Manufacturing Industry Sectors		
1	Iron and Steel	Manufacture of basic metals
	Non-ferrous Metals	
2	Chemicals and Petrochemicals	Manufacture of chemicals and chemical products
		Manufacture of basic pharmaceutical products and pharmaceutical preparations
3	Non-Metallic Minerals	Manufacture of other non-metallic mineral products
4	Food and Tobacco	Manufacture of food products; beverages and tobacco products
5	Textile and Leather	Manufacture of textiles, wearing apparel, leather and related products
6	Paper, Pulp and Print	Manufacture of paper and paper products
		Printing and reproduction of recorded media
7	Wood and Wood Products	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
8	Transport Equipment	Manufacture of other transport equipment
		Manufacture of motor vehicles, trailers and semi-trailers
9	Machinery	Manufacture of fabricated metal products, except machinery and equipment
		Manufacture of computer, electronic and optical products
		Manufacture of electrical equipment
		Manufacture of machinery and equipment
10	Construction	Construction
Transport sector		
11	Final Energy Consumption – Transport	Transportation and storage
Other Sectors		

Match No.	Electricity consumption label	GVA label
12	Fishing; Agriculture / Forestry	Agriculture, forestry and fishing
13	Services	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies
		Financial and insurance activities
		Information and communication
		Professional, scientific and technical activities; administrative and support service activities
		Public administration, defence, education, human health and social work activities
		Real estate activities
		Wholesale and retail trade, transport, accommodation and food service activities

ANNEX E MISSING DATA ANALYSIS

There were a limited number of instances in which data could not be found from the data sources used for our analysis. The table below sets out the approach taken where this has been the case.

Table E.1: CEPA Non-Domestic Missing Data Analysis

Non-Domestic VoLL Label	Missing Data / Comments	Adopted solution
Basic metals	• No non-ferrous energy consumption data for Malta. • National statistical office contacted but no response.	• Assume zero given consumption for iron and steel is zero.
	• No "manufacture of basic metals" GVA data for Luxembourg. • National statistical office contacted but no response.	• Data available for "Manufacture of basic metals and fabricated metal products, and other non-metallic mineral products – NACE divisions 24 and 25. • Assume EU28 average weight between NACE 24 and 25 GVA.
Chemical and Petrochemical	• GVA data is missing for Ireland. • National statistical office contacted but confirmed that data is not available.	• Net selling value data is available from Ireland's Central Statistics Office (CSO) but not GVA data. • Of the available data, GVA appears to be around 40% of net selling value across sectors. Assumed for now unless better data becomes available.
	• GVA data is missing for Sweden due to confidentiality. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 20 GVA in total GVA.
	• NACE 21 GVA is missing for Luxembourg.	• Data available for NACE activities 19 to 21 combined from Luxembourg national statistics office. Used to calculate residual.
	• NACE 21 GVA is missing for Malta. • National statistical office contacted but no response.	• Approach is to assume EU28 average weight (i.e. NACE 21 GVA as a proportion of total GVA).
Non-Metallic Minerals	• GVA missing for Luxembourg and Malta. • National statistical offices contacted but data not available	• Combined NACE 22 and 23 data is available for both countries. Average EU28 weight between

Non-Domestic VoLL Label	Missing Data / Comments	Adopted solution
	from Luxembourg and no response from Malta.	NACE 22 and 23 applied to obtain estimate of NACE 23 GVA.
Mining and Quarrying	• Slight mismatch between GVA and energy. GVA contains activity that energy does not: ○ B5 – Mining of coal and lignite ○ B6 – Extraction of crude petroleum and natural gas ○ B7.2.1 – Mining of uranium and thorium ores ○ B8.9.2 – Extraction of peat ○ B9.1 – Support activities for petroleum and natural gas extraction	• No solution readily available therefore VoLL estimates are omitted from report,
Paper, Pulp and Print	• NACE 17 and 18 GVA is not available for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• NACE 17, 18 and 16 combined available from Luxembourg statistics office. NACE 16 available at a disaggregate level. Therefore, NACE 16 GVA subtracted from aggregate measure, and EU28 average weight between NACE 17 and 18 applied to obtain disaggregate GVA estimates.
	• NACE 17 GVA is not available for Malta. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 17 GVA in total GVA.
Transport Equipment	• NACE 29 and 30 GVA are not available for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• Aggregate NACE 29 and 30 GVA data is available from Luxembourg statistical office, and EU28 average weight has been applied.
	• NACE 29 and 30 GVA are not available for Malta. • National statistical office contacted but no response.	• Aggregate NACE 29 and 30 GVA data is available, and EU28 average weight has been applied.
Machinery	• NACE 25 GVA is not available for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• Data available for “Manufacture of basic metals and fabricated metal products, and other non-metallic mineral products – NACE divisions 24 and 25.

Non-Domestic VoLL Label	Missing Data / Comments	Adopted solution
		• Approach is to assume EU28 average weight between NACE 24 and 25 GVA.
	• NACE 26 GVA is not available for Ireland. • National statistical office contacted but data is not available.	• Total net selling value is available from the CSO for NACE divisions 26 and 27 combined. Therefore, calculated using available data for NACE division 27 from Eurostat and assuming GVA is 40% of total net selling value based on available data.
	• NACE 26, 27 and 28 GVA is not available at a disaggregate level for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• Aggregate GVA data available from Luxembourg statistical office for NACE 26 to 28. Weighted by EU28 average weights.
	• NACE 26 and 28 GVA is not available for Malta. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 26 and 28 GVA in total GVA.
	• NACE 28 GVA is not available at a disaggregate level for Ireland. • National statistical office contacted but data is not available.	• Total net selling value is available from the CSO for NACE divisions 24, 25 and 28 combined. Therefore, calculated using available data for NACE divisions 24 and 25 from Eurostat and assuming GVA is 40% of total net selling value based on available data.
Wood and Wood Products	• NACE 16 GVA is not available at a disaggregate level for Malta. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 16 GVA in total GVA.
Construction	• Germany and Greece have reported zero electricity consumption for construction, which does not seem plausible. • National statistical offices contacted but no response received from Greece and	• Approach is to assume consumption allocated to “non-specified industry” is related to construction.

Non-Domestic VoLL Label	Missing Data / Comments	Adopted solution
	Germany have been unable to provide the requested data.	
Land Transport and transport via pipelines	• NACE 49 GVA is not available for Malta. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 49 GVA in total GVA.
	• Electricity consumption reported as zero for Malta and Cyprus. National statistical offices contacted.	• Cyprus statistical office have confirmed that electricity consumption for land transport and transport via pipelines is zero. Malta have not responded but assumed zero also.
	• France reports no “consumption in pipeline transport”.	• Assume zero and total transport consumption is met with only rail and road.
Agriculture, forestry and fishing	• Electricity consumption attributable to agriculture, forestry and fishing is reported as zero for Germany and Slovenia, which does not seem plausible. • National statistical offices have been contacted.	• Slovenia statistical office has responded by saying that this data is not available. Germany have been unable to provide the data also. • Approach taken allocates agriculture, forestry and fishing GVA to services. Thus, individual agriculture, forestry and fishing VoLL is not calculated for Slovenia and Germany.
Services (Aggregate)	• NACE 33 GVA is not available for Ireland. • National statistical office contacted but data is not available.	• Not available at a sufficiently disaggregate level to develop a good estimate from Irish data. Assumed same weight as EU28 average unless better data becomes available.
	• NACE 33 GVA is not available for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• Aggregate GVA data available from Luxembourg statistical office for NACE 31 to 33. Weighted by EU28 average weights.
	• NACE 33, 52, and 53 GVA is not available for Malta. • National statistical office contacted but no response.	• Approach is to apply EU28 average weight of NACE 33, 52 and 53 GVA in total GVA.

Non-Domestic VoLL Label	Missing Data / Comments	Adopted solution
	• NACE 52 and 53 GVA missing for Luxembourg. • National statistical office contacted but data not available at this level of disaggregation.	• Approach is to apply EU28 average weight of NACE 52 and 53 GVA in total GVA.
	• NACE 52 GVA missing for Sweden. • National statistical office contacted but no response.	• Confidential data according to Eurostat. • Approach is to apply EU28 average weight of NACE 52 GVA in total GVA.
	• NACE 53 GVA missing for Croatia. • Data requested from national statistical office and has been received.	• Received from national statistical office.
	• NACE 53 GVA missing for Poland. • National statistical office has been contacted but data is deemed confidential and has not been provided.	• Approach is to apply EU28 average weight of NACE 53 GVA in total GVA.
	• NACE 53 GVA missing for Sweden. • Confidential data according to Eurostat. Data requested from Sweden statistical office but no response received.	• Approach is to apply EU28 average weight of NACE 53 GVA in total GVA.

Source: CEPA Analysis

ANNEX F PRIMARY RESEARCH SURVEY DESIGN

Our primary research consisted of two web-based surveys – one for domestic consumers and one for non-domestic consumers. These surveys were developed and carried out in SurveyMonkey®[96]. The surveys were available in English only and were promoted through several avenues, including ACER and CEPA's own channels, NRAs and EU consumer trade bodies.

Estimating VoLL and/or WTA itself was not an objective of our primary research and this influenced the design and nature of our research accordingly. While choice experiments have a number of strengths and are more commonly used to develop WTA estimates when this is a primary motivation, a contingent valuation approach was considered the most suitable for the requirements of our analysis – for example, the identification of a substitutability and notice factor.

In addition, where relevant, our questions utilised a WTA rather than WTP approach. While triangulation using WTA and WTP is sometimes used when valuation estimates are derived from surveys, this was not the objective of our research. Using only WTA allowed us to simplify the survey and was chosen rather than WTP based on the nature of electricity supply in the EU and informed by behavioural economics literature[97].

Our surveys included questions in relation to the following:

- **Contextual information**: For domestic consumers, we requested information in relation to the country of residence, employment status and income level. For non-domestic consumers, we requested information regarding the location of the company, size of the company (SME or not), size of bill and the industry sector in which the company was active.
- **Use of electricity**: For both types of consumers, we asked questions in relation to their dependence on electricity for leisure enjoyment (domestic consumers) or productive output (non-domestic consumers) as well as how this value changed with the provision of one day of notice. We also asked respondents to indicate the times of year, week and day when they were most dependent on electricity.
- **WTA**: Finally, we asked both sets of consumers to respond to six supply interruption scenarios with the level of payment they would need to accept such a scenario. While domestic consumers were able to respond with any value of payment, non-domestic consumers were required to respond based on the percentage of their monthly bill that they would require. Non-domestic consumers were asked to respond based on a

[96] https://www.surveymonkey.com/

[97] We followed London Economics (2013). Given that electricity interruptions are infrequent in the EU, we consider that consumers will frame electricity interruptions as a loss, rather than considering improvements to electricity security to be a gain. This is supported by evidence from WTP studies which often have high levels of 'zero' WTP for greater levels of security, implying a VoLL of zero which is not considered suitable.

percentage of monthly bill in order to ensure that the various sizes of non-domestic consumers could be compared meaningfully from one consumer to the next.

Substitutability factor

Responses of both domestic and non-domestic consumers in relation to their dependence on electricity could be used to identify a substitutability factor. Respondents were presented with five options in terms of their level of dependence – 0%, 25%, 50%, 75% and 100%.

Non-domestic consumers were also asked how this valuation would change if they were provided with one day of notice ahead of the disruption. This was used as a secondary source for validation of the notice factors provided through the WTA section of the survey.

Time-varying analysis

Responses to questions relating to the timing of greatest dependence on electricity provided information to support our time-varying analysis. We did not use this to inform our primary methodology for calculation of the TSD but instead to cross-check the assumptions applied – for example surrounding the application of a flat consumption profile to non-domestic consumers.

Duration and notice

We presented respondents with the following disruption scenarios[98]:

	No notice provided before interruption	One day of notice provided before interruption
20 minutes		
2 hours		
2 days		

We selected durations of 20 minutes, 2 hours and 48 hours for two reasons:

1. We wanted to keep the number of options to three in order to ensure that the survey remained simple and to minimise completion time. Given the design of the survey, each additional duration scenario resulted in at least two additional questions. Retaining a short completion time was one of our primary objectives given the need to encourage a sufficiently high sample of respondents for statistical analysis.
2. ACER explicitly required a duration scenario of 48 hours within the terms of reference of this work. While it was expected that this scenario would be relatively rare in reality

[98] In the survey itself, these scenarios were presented sequentially rather than in combination.

within the EU, ACER wanted to select a duration scenario which may represent an upper bound on outage duration.

Where respondents were asked to state a WTA in response to an electricity interruption scenario, we were not intending to analyse the magnitude of the WTA response in isolation. Hence, we did not use responses to derive a VoLL or WTA estimate.

Instead, we designed the survey in order to explore the relative difference between responses to inform our analysis of the impacts of duration of the interruption and the provision of notice. We were also able to consider how the notice factor changed depending on the duration of supply interruption that would subsequently be experienced – i.e. we could measure how useful one day of notice was for consumers in relation to an interruption lasting 20 minutes in comparison to an interruption of 2 days.

ANNEX G VOLL AND VOLA ESTIMATES BY MEMBER STATE

We present the results of VoLL and VoLA in each EU MS in the tables below. A discussion of these results can be found in Section 6.

Table G.1: Domestic VoLL and VoLA estimates

Member State	Annual average VoLL (€/kWh)[99]	VoLA (€/kWh)
Austria	9.01	5.00
Belgium	9.60	5.33
Bulgaria	1.50	0.83
Croatia	3.15	1.75
Cyprus	6.19	3.44
Czech Republic	3.53	1.96
Denmark	15.73	8.73
Estonia	5.18	2.87
Finland	5.30	2.94
France	6.92	3.84
Germany	12.41	6.89
Greece	4.24	2.35
Hungary	3.27	1.82
Ireland	11.52	6.39
Italy	11.34	6.29
Latvia	4.71	2.61
Lithuania	4.62	2.56
Luxembourg	13.52	7.51
Malta	6.38	3.54
Netherlands	22.94	12.73
Poland	6.26	3.47
Portugal	5.89	3.27
Romania	4.52	2.51
Slovakia	4.73	2.62
Slovenia	4.32	2.40
Spain	7.88	4.37
Sweden	5.52	3.06
United Kingdom	15.90	8.83

[99] All values are in 2015 Euros unless otherwise stated.

Table G.2: Non-domestic VoLL (€/kWh) estimates

Member State	Basic Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, Pulp and Print	Wood and Wood Products
Austria	0.90	0.89	1.12	2.08	2.18	0.50	1.15
Belgium	0.33	0.93	0.69	1.17	1.03	0.67	1.56
Bulgaria	0.16	0.33	0.37	0.78	1.52	0.51	0.52
Croatia	0.25	1.45	0.46	1.73	1.62	0.90	0.72
Cyprus	5.06	2.14	0.45	1.27	1.97	1.85	5.31
Czech Republic	0.45	0.48	0.66	1.68	0.86	0.57	1.54
Denmark	0.72	6.16	1.22	1.05	2.52	1.86	2.07
Estonia	2.14	0.67	0.70	1.00	1.42	0.28	1.03
Finland	0.20	0.58	1.24	1.26	2.51	0.16	0.75
France	0.23	1.23	0.75	1.83	2.44	0.90	1.03
Germany	0.41	1.06	1.11	2.00	2.64	0.71	1.30
Greece	0.24	1.95	0.63	2.38	1.98	0.65	0.33
Hungary	0.46	0.67	0.43	0.75	1.60	0.61	0.75
Ireland	0.34	10.77	0.70	3.58	1.06	2.07	0.37
Italy	0.31	1.13	0.84	1.76	3.63	0.86	1.23
Latvia	0.37	1.86	0.59	1.58	3.21	3.10	0.63
Lithuania	0.86	0.79	0.80	1.68	2.60	1.57	1.13
Luxembourg	0.07	0.22	0.88	1.42	1.50	1.48	4.63
Malta	*	1.53	3.23	1.84	0.36	3.00	9.23
Netherlands	0.31	0.73	1.18	1.77	2.46	0.95	3.25
Poland	0.22	0.52	0.73	1.69	3.57	0.75	1.05
Portugal	0.16	0.53	0.52	1.68	2.43	0.35	1.51
Romania	0.17	0.38	0.41	3.23	3.28	0.87	0.81
Slovakia	0.15	0.38	0.81	1.51	3.75	0.57	4.28
Slovenia	0.16	1.59	0.56	1.43	1.96	0.38	1.30
Spain	0.28	1.51	0.72	2.07	2.65	0.84	1.38
Sweden	0.34	1.42	1.30	1.56	1.98	0.19	1.04
United Kingdom	0.51	1.69	0.90	2.78	2.61	0.99	5.27

** Unable to estimate VoLL due to limited data. The results for the Mining and Quarrying sector did not pass our data verification procedures so have not been included.*

Table G.3: Non-domestic VoLL (€/kWh) estimates, continued

Member State	Transport Equipment	Machinery	Construction	Transport	Agriculture, Forestry and Fishing	Services
Austria	5.46	5.24	22.09	3.12	2.25	10.43
Belgium	1.25	13.77	18.61	3.96	1.22	8.76
Bulgaria	1.93	1.27	5.27	3.09	5.78	2.12
Croatia	1.90	2.61	21.40	2.87	17.26	3.25
Cyprus	1.74	5.45	113.00	*	1.55	4.65
Czech Republic	2.54	2.81	14.47	2.27	2.65	4.07
Denmark	4.39	6.68	24.62	9.66	0.83	11.59
Estonia	1.48	2.41	10.96	16.10	1.84	2.86
Finland	2.17	5.21	25.12	5.25	2.06	4.86
France	3.23	3.17	12.91	3.07	2.72	7.15
Germany	6.09	5.59	5.86	3.71	*	8.55
Greece	2.05	10.85	1.03	11.30	1.99	4.51
Hungary	2.47	2.35	10.83	2.06	3.24	4.91
Ireland	1.21	3.98	68.48	39.00	2.86	13.97
Italy	4.32	3.35	42.30	6.41	3.99	7.83
Latvia	1.50	4.26	15.15	6.67	3.64	3.76
Lithuania	5.29	3.86	13.75	29.73	4.57	4.47
Luxembourg	4.14	8.76	13.53	6.98	2.21	13.34
Malta	2.65	1.83	10.16	*	5.96	4.48
Netherlands	6.30	6.33	26.41	5.64	0.88	8.91
Poland	2.53	3.04	29.88	3.85	4.29	3.53
Portugal	3.10	2.34	16.41	8.15	2.94	4.57
Romania	2.05	2.24	16.92	5.76	4.97	6.53
Slovakia	2.55	2.82	67.97	5.00	6.93	4.16
Slovenia	2.56	2.18	33.13	6.19	*	4.66
Spain	4.15	4.76	21.47	4.73	3.19	6.64
Sweden	5.00	4.43	15.31	3.05	2.92	7.01
United Kingdom	5.53	3.66	83.49	7.51	2.56	13.05

** Unable to estimate VoLL due to limited data.*

Table G.4: Non-domestic VoLA (€/kWh) estimates

Member State	Basic Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, Pulp and Print	Wood and Wood Products
Austria	0.71	0.71	0.88	1.64	1.72	0.39	0.91
Belgium	0.26	0.73	0.54	0.92	0.81	0.53	1.23
Bulgaria	0.13	0.26	0.29	0.61	1.20	0.40	0.41
Croatia	0.20	1.15	0.37	1.37	1.28	0.71	0.57
Cyprus	3.99	1.69	0.36	1.00	1.56	1.46	4.19
Czech Republic	0.36	0.38	0.52	1.32	0.68	0.45	1.21
Denmark	0.57	4.86	0.96	0.83	1.99	1.46	1.63
Estonia	1.69	0.53	0.55	0.79	1.12	0.22	0.81
Finland	0.16	0.45	0.97	0.99	1.98	0.13	0.60
France	0.18	0.97	0.59	1.44	1.92	0.71	0.81
Germany	0.33	0.84	0.87	1.58	2.08	0.56	1.03
Greece	0.19	1.54	0.50	1.88	1.56	0.51	0.26
Hungary	0.36	0.53	0.34	0.60	1.26	0.48	0.59
Ireland	0.27	8.50	0.55	2.83	0.84	1.63	0.29
Italy	0.25	0.89	0.66	1.39	2.86	0.68	0.97
Latvia	0.29	1.46	0.47	1.24	2.53	2.44	0.50
Lithuania	0.68	0.62	0.63	1.33	2.05	1.23	0.89
Luxembourg	0.06	0.18	0.70	1.12	1.18	1.17	3.66
Malta	*	1.21	2.55	1.45	0.28	2.37	7.28
Netherlands	0.25	0.57	0.93	1.40	1.94	0.75	2.56
Poland	0.17	0.41	0.58	1.33	2.82	0.59	0.83
Portugal	0.13	0.42	0.41	1.33	1.91	0.28	1.19
Romania	0.14	0.30	0.32	2.55	2.59	0.69	0.64
Slovakia	0.12	0.30	0.64	1.19	2.96	0.45	3.37
Slovenia	0.13	1.25	0.44	1.13	1.54	0.30	1.02
Spain	0.22	1.19	0.56	1.63	2.09	0.66	1.09
Sweden	0.27	1.12	1.03	1.23	1.57	0.15	0.82
United Kingdom	0.40	1.33	0.71	2.20	2.06	0.78	4.16

** Unable to estimate VoLA due to limited data. The results for the Mining and Quarrying sector did not pass our data verification procedures so have not been included.*

Table G.5: Non-domestic VoLL (€/kWh) estimates, continued

Member State	Transport Equipment	Machinery	Construction	Transport	Agriculture, Forestry and Fishing	Services
Austria	4.31	4.13	17.43	2.46	1.39	6.46
Belgium	0.98	10.87	14.68	3.13	0.75	5.42
Bulgaria	1.52	1.00	4.15	2.43	3.58	1.31
Croatia	1.50	2.06	16.89	2.26	10.68	2.01
Cyprus	1.37	4.30	89.15	*	0.96	2.88
Czech Republic	2.00	2.22	11.42	1.79	1.64	2.52
Denmark	3.46	5.27	19.43	7.63	0.52	7.17
Estonia	1.17	1.90	8.65	12.70	1.14	1.77
Finland	1.71	4.11	19.82	4.14	1.28	3.01
France	2.55	2.50	10.18	2.42	1.68	4.43
Germany	4.80	4.41	4.62	2.93	*	5.29
Greece	1.62	8.56	0.81	8.91	1.23	2.79
Hungary	1.95	1.86	8.55	1.63	2.00	3.04
Ireland	0.96	3.14	54.03	30.77	1.77	8.65
Italy	3.41	2.64	33.37	5.06	2.47	4.85
Latvia	1.18	3.36	11.96	5.26	2.25	2.32
Lithuania	4.17	3.05	10.85	23.45	2.83	2.77
Luxembourg	3.27	6.91	10.68	5.51	1.37	8.26
Malta	2.09	1.44	8.01	*	3.69	2.77
Netherlands	4.97	5.00	20.83	4.45	0.55	5.52
Poland	2.00	2.40	23.57	3.03	2.65	2.19
Portugal	2.45	1.84	12.95	6.43	1.82	2.83
Romania	1.62	1.77	13.35	4.55	3.08	4.04
Slovakia	2.01	2.23	53.63	3.94	4.29	2.58
Slovenia	2.02	1.72	26.14	4.89	*	2.89
Spain	3.27	3.75	16.94	3.73	1.98	4.11
Sweden	3.95	3.50	12.08	2.41	1.81	4.34
United Kingdom	4.37	2.89	65.87	5.92	1.58	8.08

** Unable to estimate VoLA due to limited data.*

ANNEX H ANALYSIS OF DISAGGREGATED SERVICES SECTORS

While we consider that the consumer segmentation presented in the main report represents a suitable level of disaggregation, we have noted that the 'Services' sector in particular may represent a heterogenous collection of consumers. While EU-wide data does not allow for further disaggregation, we have identified a limited number of EU MS that present consumption data for the Services sector at a more disaggregated level.

In four cases, we have identified consumption data which can be mapped onto the GVA labels used by Eurostat with a sufficient level of accuracy to allow for meaningful analysis[100]. We do however urge caution with interpretation of these results. As the data is taken from national statistical offices, there may be inconsistencies in the definitions applied from one MS to the next. We therefore assign a lower level of confidence to the quality of data and consistency of sector definitions relative to the aggregated headline estimates for the Services sector provided in Section 6. We present our findings in the table below and in Figure H.1.

Table H.1: Disaggregated Services sector VoLL (€/kWh) estimates for selected MS

Service sector	Cyprus	Estonia	Netherlands	Sweden
Repair and Installation	2.81	3.49	12.03	11.10
Water Supply	0.40	1.00	1.14	1.37
Trade	3.06	1.80	6.58	4.93
Transportation support	2.90	2.11	2.82	4.87
Hotels and Restaurants	1.60	0.94	2.45	2.54
Information and Communication	4.95	5.07	7.45	22.39
Financial and Insurance	23.93	33.65	21.05	30.48
Professional and Scientific	7.13	11.02	28.78	23.77
Administration	24.41	10.10	41.59	5.60
Public admin and Defence	*	3.19	8.31	9.26
Education	18.16	10.12	12.77	6.93
Health	4.77	3.61	10.21	11.79
Arts and Entertainment	3.60	4.16	3.56	2.67

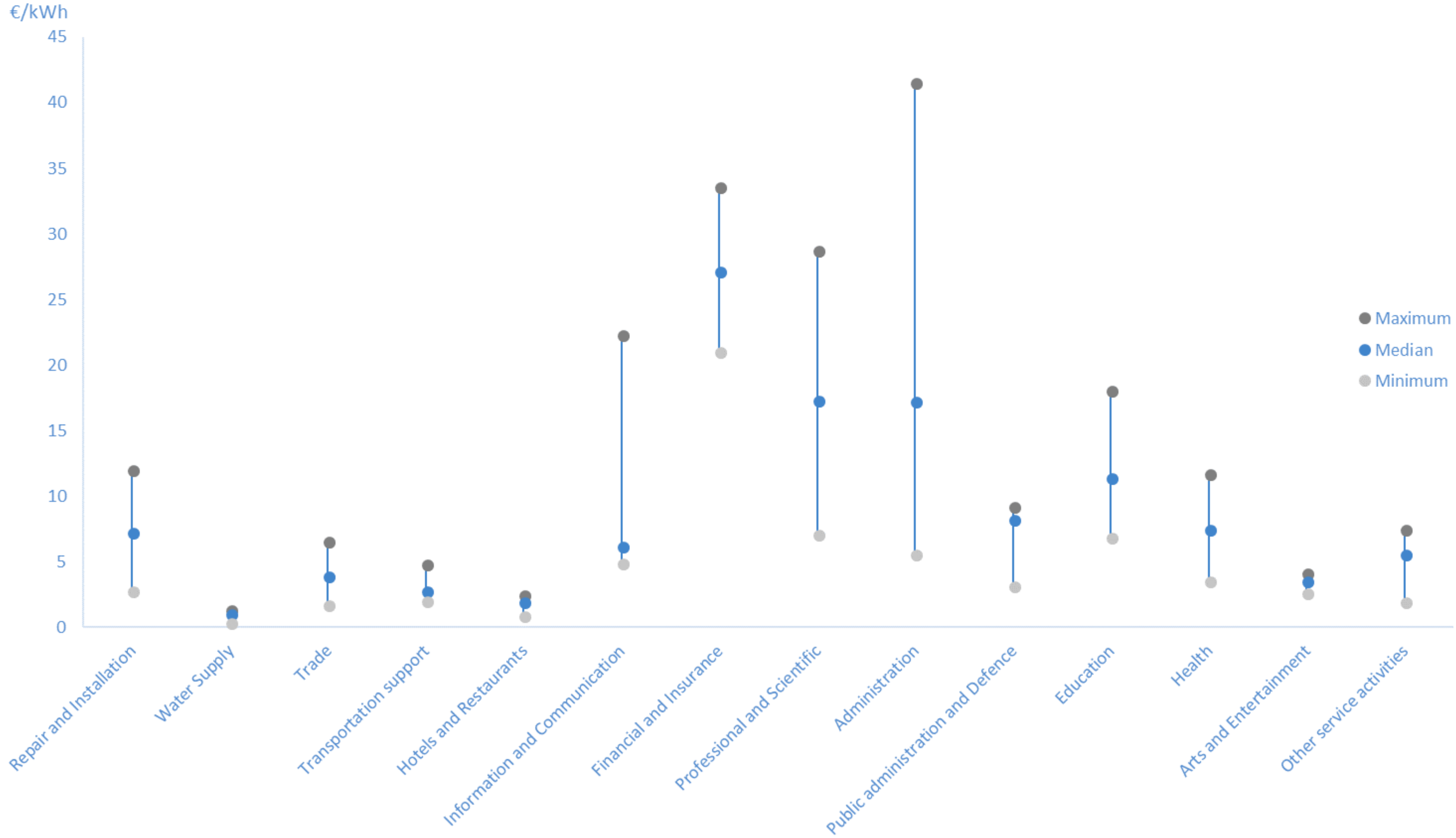
[100] We identify national disaggregated data for a further two MS, however discrepancies between consumption levels reported at national and EU level mean that we are not sufficiently confident in the accuracy and consistency of this data to include results.

Service sector	Cyprus	Estonia	Netherlands	Sweden
Other service activities	2.00	5.96	7.50	5.32

** This result and the results for the Real Estate sector for all MS have been excluded as they failed our data validity checks.*

We find that the Financial and Insurance sector has the highest VoLL in each MS, with Administration also reporting a high VoLL estimate. We find that the Water Supply sector has the lowest VoLL within the Services sectors.

Figure H.1: Estimated Services VoLL range by disaggregated sector



Source: CEPA Analysis

ANNEX I SENSITIVITY ANALYSIS

Our primary research allowed us to inform many of our assumptions based on the stated preferences of consumers from across the EU. However, in two cases, we have considered it beneficial to carry out analysis of the sensitivity of our results to different assumptions.

1. **Non-employment factor**: The sample size of individuals who were not employed was not sufficient to draw conclusions regarding the value that they place on leisure relative to employed consumers (i.e. the non-employment factor). We therefore considered the impact of varying the non-employment factor on domestic VoLL in our first sensitivity.
2. **Substitutability factor of consumers in the Industry sectors**: Given the size of the sample of consumers in Industry sectors, we took the average of the sector as a whole for our primary assumption. However, noting that a majority of these consumers stated a substitutability factor of 100%, we considered the impact of using such an assumption in our second sensitivity.

I.1. Sensitivity 1: Varying the non-employment factor

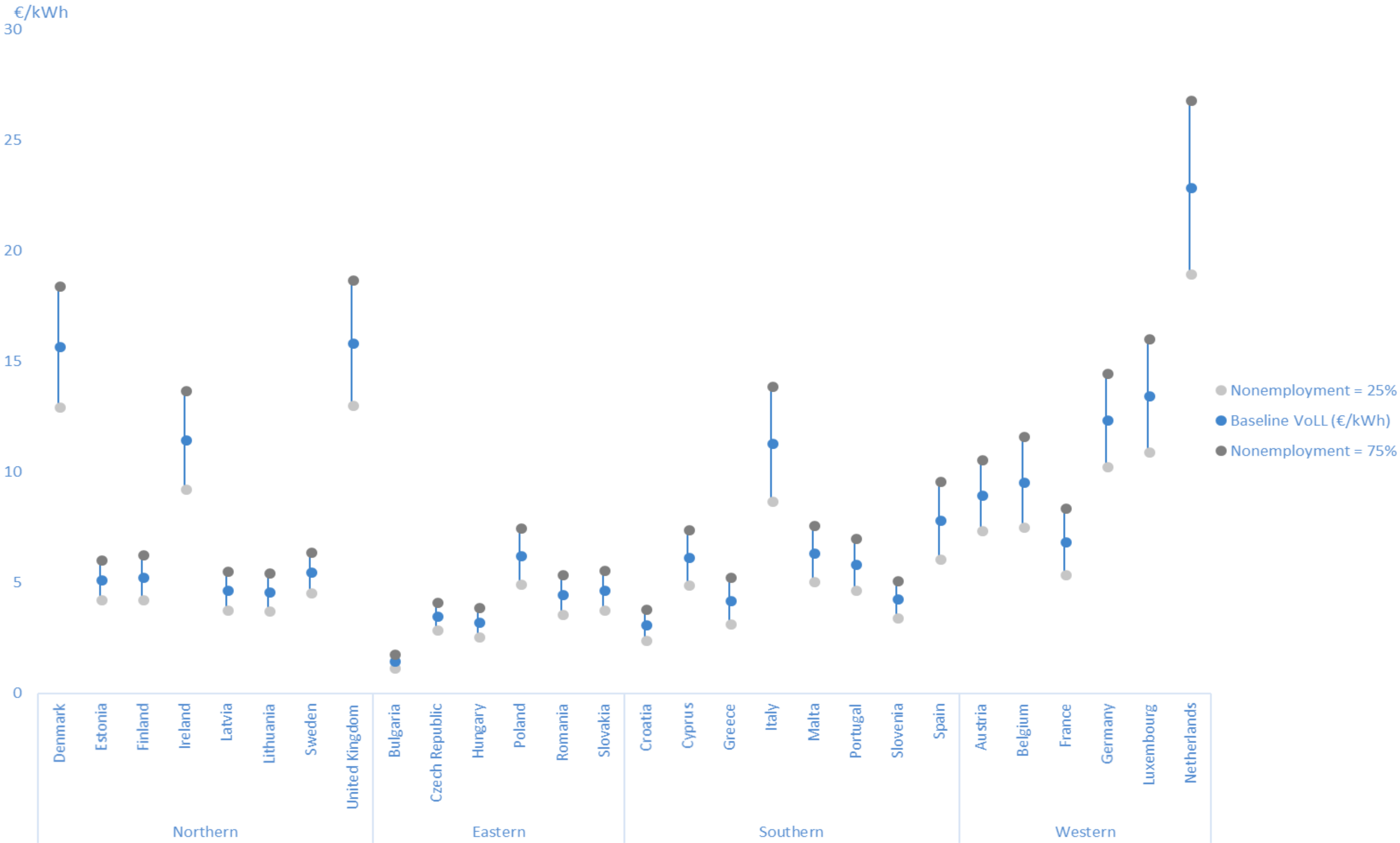
The non-employment factor reflects the fact that those who are not employed (the unemployed, retired, students and disabled) are likely to report a lower valuation of their leisure time on average[101]. For our headline VoLL analysis, we followed assumptions used in previous literature of a non-employment factor of 50%. However, we wanted to test the sensitivity of this assumption by considering a non-employment factor of 25% and 75%. In the table below, we report the results of this sensitivity analysis.

[101] This may reflect two things. Firstly, that those who are not employed have more leisure time and so value each unit less highly. Secondly, that those who are not employed are likely to have a lower level of income which generally correlates with WTA a supply disruption.

Table I.1: Non-employment factor sensitivity analysis – Domestic VoLL estimates

Member State	Nonemployment factor = 25%	Baseline VoLL (€/kWh)	Nonemployment factor = 75%
Austria	7.43	9.01	10.60
Belgium	7.56	9.60	11.65
Bulgaria	1.19	1.50	1.81
Croatia	2.43	3.15	3.86
Cyprus	4.94	6.19	7.45
Czech Republic	2.91	3.53	4.16
Denmark	13.00	15.73	18.46
Estonia	4.28	5.18	6.07
Finland	4.28	5.30	6.32
France	5.42	6.92	8.42
Germany	10.29	12.41	14.53
Greece	3.18	4.24	5.31
Hungary	2.62	3.27	3.93
Ireland	9.28	11.52	13.75
Italy	8.73	11.34	13.95
Latvia	3.83	4.71	5.59
Lithuania	3.76	4.62	5.48
Luxembourg	10.96	13.52	16.09
Malta	5.10	6.38	7.66
Netherlands	19.02	22.94	26.87
Poland	4.98	6.26	7.54
Portugal	4.72	5.89	7.06
Romania	3.62	4.52	5.43
Slovakia	3.82	4.73	5.63
Slovenia	3.48	4.32	5.15
Spain	6.13	7.88	9.63
Sweden	4.58	5.52	6.45
United Kingdom	13.08	15.90	18.73

Figure I.1: Domestic VoLL sensitivity analysis ranges, grouped by region



Source: CEPA Analysis

I.2. Sensitivity 2: Industrial substitutability factor of 100% - VoLL estimates

We used results of our primary research to define a substitutability factor for non-domestic consumers. We found evidence to suggest that consumers in the Industry sectors had a higher substitutability factor (80.9%) than those in the Services sectors (68.2%). Given the sample size, we used the mean of the reported substitutability factors within each to define the factor used for our headline VoLL analysis. However, we also noted that a significant majority of Industrial consumers (more than 60%) reported a substitutability factor of 100% and that this was particularly pronounced for some industries (e.g. consumers in the Chemicals and Petrochemicals sectors had a mean substitutability factor of more than 90%). In order to assess the sensitivity of our VoLL estimates for the Industrial sector to the assumption, we have developed estimates of VoLL using a 100% substitutability factor for Industry sectors. Results are presented in Table I.2 below.

Table I.2: Industrial VoLL, substitutability factor = 100%

Member State	Basic Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, pulp and print	Wood and Wood Products
Austria	1.12	1.11	1.38	2.57	2.70	0.62	1.42
Belgium	0.41	1.15	0.85	1.44	1.28	0.82	1.93
Bulgaria	0.20	0.41	0.45	0.96	1.88	0.63	0.64
Croatia	0.31	1.80	0.57	2.14	2.00	1.11	0.89
Cyprus	6.25	2.65	0.56	1.57	2.44	2.28	6.56
Czech Republic	0.56	0.60	0.82	2.07	1.06	0.71	1.90
Denmark	0.89	7.61	1.51	1.30	3.11	2.29	2.55
Estonia	2.64	0.83	0.87	1.24	1.75	0.35	1.28
Finland	0.25	0.71	1.53	1.55	3.11	0.20	0.93
France	0.28	1.53	0.92	2.26	3.02	1.11	1.28
Germany	0.51	1.31	1.37	2.47	3.26	0.88	1.61
Greece	0.29	2.41	0.78	2.94	2.44	0.80	0.41
Hungary	0.57	0.83	0.53	0.93	1.98	0.75	0.93
Ireland	0.42	13.31	0.86	4.43	1.31	2.56	0.46
Italy	0.39	1.40	1.04	2.17	4.48	1.06	1.52
Latvia	0.45	2.29	0.73	1.95	3.97	3.83	0.78
Lithuania	1.07	0.98	0.99	2.08	3.22	1.93	1.39
Luxembourg	0.09	0.28	1.09	1.76	1.85	1.83	5.73
Malta	*	1.89	3.99	2.27	0.45	3.71	11.41
Netherlands	0.38	0.90	1.46	2.19	3.04	1.18	4.01

Member State	Basic Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, pulp and print	Wood and Wood Products
Poland	0.27	0.65	0.91	2.09	4.41	0.92	1.30
Portugal	0.20	0.65	0.65	2.08	3.00	0.43	1.86
Romania	0.22	0.46	0.50	3.99	4.05	1.08	1.00
Slovakia	0.18	0.47	1.00	1.87	4.64	0.71	5.28
Slovenia	0.20	1.96	0.69	1.77	2.42	0.47	1.61
Spain	0.35	1.87	0.88	2.56	3.27	1.04	1.70
Sweden	0.42	1.76	1.61	1.92	2.45	0.23	1.29
United Kingdom	0.63	2.09	1.12	3.44	3.23	1.22	6.51

** Unable to estimate VoLL due to limited data.*

Table I.3: Industrial VoLL, substitutability factor = 100%, continued

Member State	Transport Equipment	Machinery	Construction	Transport
Austria	6.74	6.48	27.31	3.85
Belgium	1.54	17.03	23.00	4.90
Bulgaria	2.39	1.57	6.51	3.81
Croatia	2.35	3.22	26.46	3.55
Cyprus	2.15	6.74	139.68	*
Czech Republic	3.14	3.47	17.89	2.81
Denmark	5.43	8.26	30.43	11.95
Estonia	1.83	2.98	13.55	19.90
Finland	2.68	6.44	31.05	6.49
France	3.99	3.91	15.95	3.79
Germany	7.53	6.91	7.24	4.59
Greece	2.53	13.41	1.28	13.96
Hungary	3.05	2.91	13.39	2.55
Ireland	1.50	4.91	84.64	48.20
Italy	5.33	4.14	52.28	7.92
Latvia	1.85	5.27	18.73	8.25
Lithuania	6.53	4.78	16.99	36.74
Luxembourg	5.12	10.83	16.73	8.63
Malta	3.28	2.26	12.55	*
Netherlands	7.79	7.83	32.64	6.97
Poland	3.13	3.76	36.93	4.75
Portugal	3.83	2.89	20.29	10.07
Romania	2.53	2.77	20.92	7.12
Slovakia	3.16	3.49	84.02	6.18
Slovenia	3.17	2.70	40.96	7.66
Spain	5.13	5.88	26.53	5.85
Sweden	6.18	5.48	18.92	3.77
United Kingdom	6.84	4.52	103.20	9.28

** Unable to estimate VoLL due to limited data.*