STUDY ON THE VALUE OF LOST LOAD OF ELECTRICITY SUPPLY IN EUROPE - ACER

Cambridge Economic Policy Associates

Presentation of findings – Brussels

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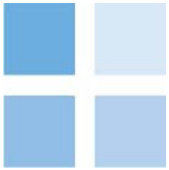

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1 CONTEXT

Cambridge Economic Policy Associates (CEPA)

CEPA

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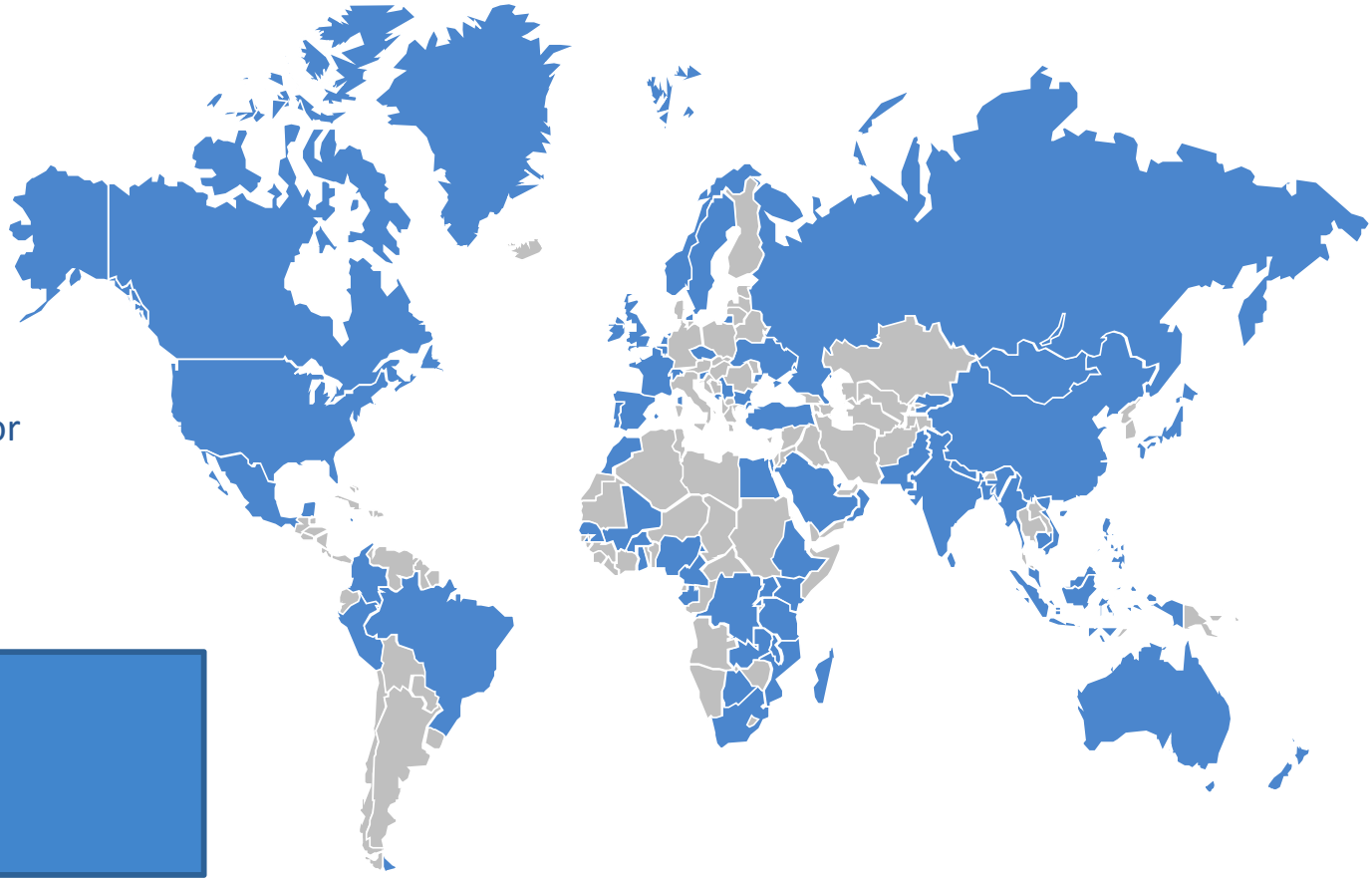
CEPA, from its offices in London and Sydney, advises a wide range of clients, including government departments, sector regulators, international organisations, non-governmental organisations, foundations, private sector companies and consumer groups across every continent.



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Context

Process so far – Thanks to those who have supported our work

December 2017	• CEPA commissioned to undertake project
February 2018	• Task B preliminary report submitted to ACER and NRAs for comment
April 2018	• Task A report submitted following ACER and NRA comment
May 2018	• Task A and B draft report submitted for ACER and NRA comment
22 June 2018	• Task A and B final report due for submission

Context

Aims for this workshop

- To provide you with an understanding of our methodology
- To present our results
- To discuss limitations of our research
- To explore practical applications of our findings

Scope of discussion

- The final report is due on Friday (22nd June)
- Thank to those NRAs who have provided comments on our draft report (8th June)
- Minor presentational changes can be incorporated following this workshop
- However, revisions to the methodology or the addition of new analysis is not within scope

Context

VoLL and VoLA

Value of lost load (VoLL)

"The value attributed by consumers to unsupplied energy"

The European Union Electricity Market Glossary

Value of lack of adequacy (VoLA)

"The value attributed by consumers to unsupplied energy given advance notification"

ACER/CEPA definition*

**NB: For this project, ACER specified consideration of advance notice of one day*

Objectives

Two key objectives

1. Review and assess the concept of VoLL in electricity supply:

- Conduct review of academic literature
- Analyse and identify relevant consumer types
- Group these into groups of meaningful homogeneity

2. Provide numerical estimates of VoLL for each consumer type/group per Member State:

- Take into account individual MS specificities
- Consider the context of different regulatory applications
- Evaluate the opportunity to differentiate VoLL by impact of timing, duration and provision of notice

In this presentation, we focus on the VoLL estimates that we have derived (i.e. objective 2)

2 METHODOLOGY

Methodology

Two analytical methodologies employed

1. Primary approach: Production-function methodology

- Used to develop 'headline' VoLL estimates
- Based on the assumption that electricity is a fundamental input for the enjoyment of leisure and for productive output
- Made use of publicly available EU data
- Best placed to meet ACER's objectives: Allowed consistent and objective approach covering all consumers in the EU

2. Supporting research: Domestic and non-domestic consumer surveying

- Designed to support primary methodology
- Used to refine key assumptions
- Also used to evaluate additional requirements – e.g. impact of duration of outage and notice
- Was not intended to develop VoLL estimates

Methodology

Production-function: Analytical steps

1. Evaluation of market segmentation
2. Estimation of VoLL (domestic)
3. Estimation of VoLL (non-domestic)
4. Estimation of VoLA (domestic and non-domestic)
5. Time Specific Dependence (TSD) analysis

Methodology

Production-function methodology: VoLL Calculation

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.
- 1c: Develop assumptions of the 'substitutability factor': the proportion of leisure value that is reliant on the supply of electricity.
- 1d: Apply assumption regarding the value of leisure time for non-employed individuals (the 'non-employment' factor).

Step 2: Calculate average household VoLL for each MS

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

Methodology

Production-function methodology: VoLL Calculation

Step 1a: Estimate time spent on leisure activities

- To estimate the value of leisure to households, we need to estimate the time they spend on leisure activities:

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

- Personal care includes sleeping, washing and eating. The implicit simplifying assumption is that these activities do not require electricity.

Methodology

Production-function methodology: VoLL Calculation

Step 1b: Calculate value of leisure for the employed

- We assume that VoLL of household consumers is driven primarily by the interruption of leisure (defined in the broadest sense)
  - Damage costs for interruptions of short duration are not incorporated directly within the methodology. Impact on results limited by:
    - Consumer preferences for battery based electronic devices and other technologies that limit damage resulting from 'unsaved' files
    - Given that UK food safety standards suggest a refrigerator will keep cold for four hours without power
- Assume that individuals are indifferent between an additional unit of labour and additional unit of leisure at the margin and that the marginal unit of labour is interrupted by an outage.

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

Methodology

Production-function methodology: VoLL Calculation

Steps 1c and 1d: The substitutability factor and non-employed coefficient

- Without incorporating additional assumptions, our estimate of leisure value would have two limitations:
  1. It assumes that 100% of the value of leisure is dependent on electricity
  2. It assumes that those who are not employed value an hour of leisure at the same level as those who are employed.

- We incorporate these considerations into our analysis using two coefficients:
  - **Substitutability factor (s.f.)**: Reflects the proportion of leisure that is dependent on electricity. A high s.f. (close to 100%) represents a high level of dependence on electricity.
  - **Non-employed coefficient**: Reflects the lower value placed on an hour of leisure by those who are not employed.

Previous literature has generally assumed s.f. and non-employed coefficients of 50%

Methodology

Production-function methodology: VoLL Calculation

Steps 1c and 1d: The substitutability factor and non-employed coefficient

- Using the s.f. and non-employed coefficient, we can identify the total value of leisure that is dependent on electricity for each Member State:

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

Methodology

Production-function methodology: VoLL Calculation

Step 2: Calculate average household VoLL for each MS

- To determine average VoLL for households in each MS, we can divide the total annual leisure value by the total annual household consumption:

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

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

Methodology

The impact of notice ahead of an outage

Calculating Value of Lack of Adequacy (VoLA)

- To incorporate the impact of providing one day of notice ahead of an outage, we can introduce a new factor into our equation.
- We define the 'notice factor'.
- This captures the reduced impact on the value of leisure (e.g. due to re-planning leisure activities) by providing one day of notice ahead of the interruption.
- As with the s.f., a high notice factor (close to one), indicates that dependence on electricity remains high even when notice is provided.

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

Methodology

The impact of duration

Considering outages of different duration

- We have evaluated the relative impact of outages of differing durations by comparing willingness to accept of consumers in response to outages of three durations:
  - 20 minutes
  - 2 hours
  - 48 hours
- We have also combined this with consideration of notice to evaluate the combined impact of notice and duration – e.g. considering whether the value of notice changes depending on the duration of the outage.

Methodology

Time-specific dependence analysis

To consider the time-specific nature of dependence on electricity, we use the demand factor:

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

This allowed us to define the TSD:

$$TSD = VoLL \times Demand\ factor$$

Time dimensions considered for TSD analysis

Time of day

- Day (8am to 8pm)
- Night (8pm to 8am)

Day of week

- Weekday
- Saturday
- Sunday

Time of year

- Spring
- Summer
- Autumn
- Winter

Methodology

Non-domestic consumer analysis

- Conceptually similar for non-domestic and domestic consumers
- Rather than the value of leisure, we consider the impact of an outage on productive output, measured using gross value added (GVA)

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

- We also make use of an s.f. for non-domestic consumers.
- However , we expected that this would be different to that of domestic consumers
  - Previous literature has often used an s.f. of 100%. i.e. the assumption is that non-domestic consumers are completely dependent on electricity and that all output would stop in the event of an outage

3 KEY ASSUMPTIONS, PARAMETERS AND LIMITATIONS

Assumptions

Use of primary research

- Three main objectives:

1. **Refining baseline assumptions**: e.g. of the s.f.
2. **Informing additional analysis**: Considering the impacts of notice and duration on VoLL/VoLA.
3. **Understand differentiation of assumptions based on region or consumer characteristics.**

- **Our primary research was designed as following:**
  - Two online surveys presented in English using SurveyMonkey®
  - Where questions required a consumer valuation, they were based on:
    - Contingent valuation with open responses
    - Willingness to accept (based on behavioural economics theory)

Assumptions

Use of primary research

- Primary research has supported our analysis in a number of areas:

Assumption	Role of primary research	Impact on analysis
Substitutability factor (domestic)	Refined 50% assumption used in literature	Revised s.f. with potential for differentiation between consumers
Substitutability factor (non-domestic)	Refined 100% assumption used in literature	Revised s.f. with potential for differentiation between consumers
Notice factor (all)	Provided evidence base for evaluation of VoLA	Incorporated evidenced notice factor into analysis
Impact of duration (all)	Evaluated WTA in response to a range of outage durations	Considered impact of duration on WTA, and interaction with provision of notice
Time specific dependence analysis (all)	Corroborated TSD analysis	Supported consideration of time specific analysis in EU and U.K.

Parameters

Market segmentation – non-domestic

- Domestic consumers were considered as a single homogeneous group
- Inputs into our market segmentation included our review of the literature and our appraisal of available data – e.g. from Eurostat.

Manufacturing industries	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 • *(Services sector segmented further in the case of four MS)*

Parameters

Member State Categorisation - Regions

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	

Parameters

Member State Categorisation – Relative income

Above median income	Below median 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

Primary research draft findings

Use of primary research – Response assessment

Domestic survey:

- Number of responses: >600
- Respondents who answered all questions: >500
- Regional contribution:
  - At least one response from all MS apart from Malta
  - 17 MS submitted at least 10 responses
  - Six MS submitted at least 50 responses

Primary research draft findings

Use of primary research – Response assessment

Non-domestic survey:

- Number of responses: 123
- Respondents who answered all questions: 77
- Regional contribution:
  - Six MS had zero responses
  - 13 MS provided four or more responses
- Sectoral contribution:
  - All sectors submitted at least one response save for ‘Fishing’
  - Eight sectors provided at least five responses
  - 31 responses stated that they were small- and medium-sized enterprises (SMEs)

Primary research draft findings

Stated substitutability factors (s.f.) - Domestic

- The s.f. represents the extent to which domestic consumers are dependent on electricity for their leisure. A higher substitutability factor represents greater dependence.
- The literature has often assumed an s.f. of 50%

	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%

- We find a statistically different s.f. for North-EU MS and MS outside of northern Europe.

We have used an s.f. of 63.1% for northern European MS and 58.3% for all other MS

Primary research draft findings

S.f. – Non-domestic

- For non-domestic consumers, the literature has often assumed an s.f. of 100% - i.e. that production is completely dependent on electricity

	Disaggregation	Responses	Average substitutability factor
Overall		**103**	**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%

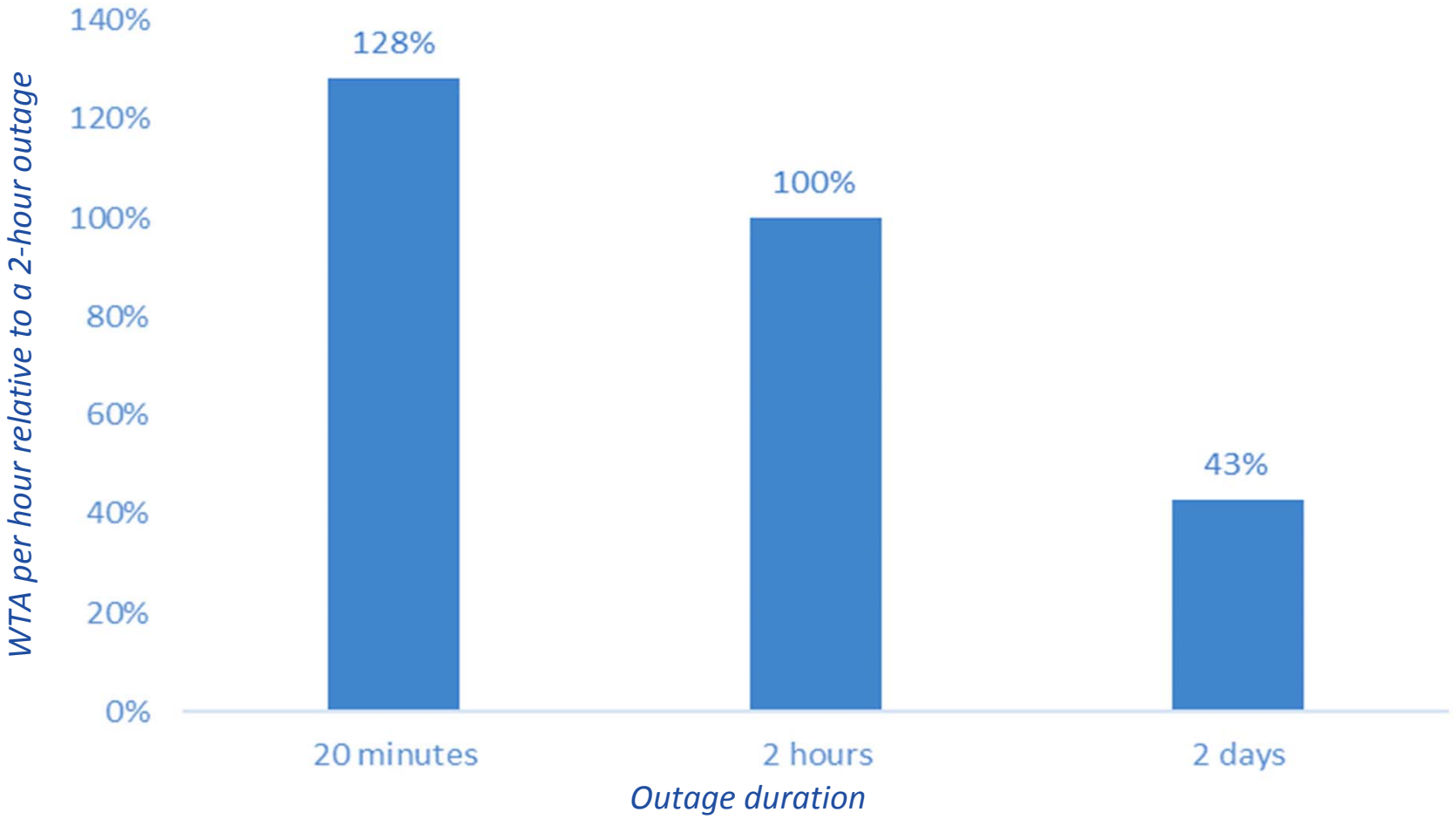
- We find that the s.f. for non-domestic consumers is indeed higher than for domestic consumers.
- However, we find that for consumers in the Industrial (and particularly Services) sectors, the s.f. is lower than 100%.

We apply an s.f. of 80.9% for Industrial consumers and 68.2% for Services consumers

Primary research draft findings

Impact of duration of outage on WTA - Domestic

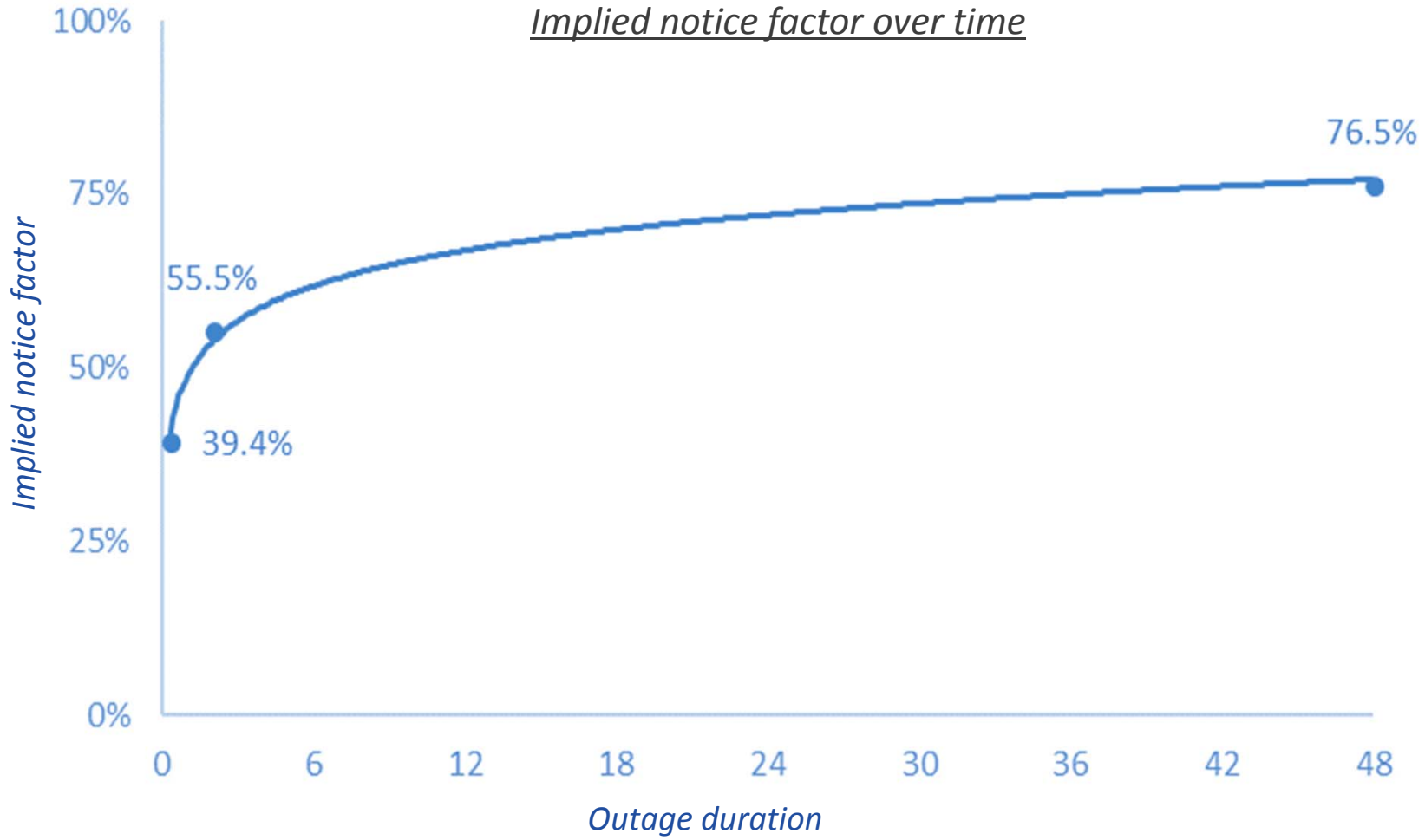
Domestic WTA per hour relative to a 2-hour outage WTA



WTA increases but marginal WTA decreases with duration of outage

Primary research draft findings

Impact of notice (VoLA) - Domestic

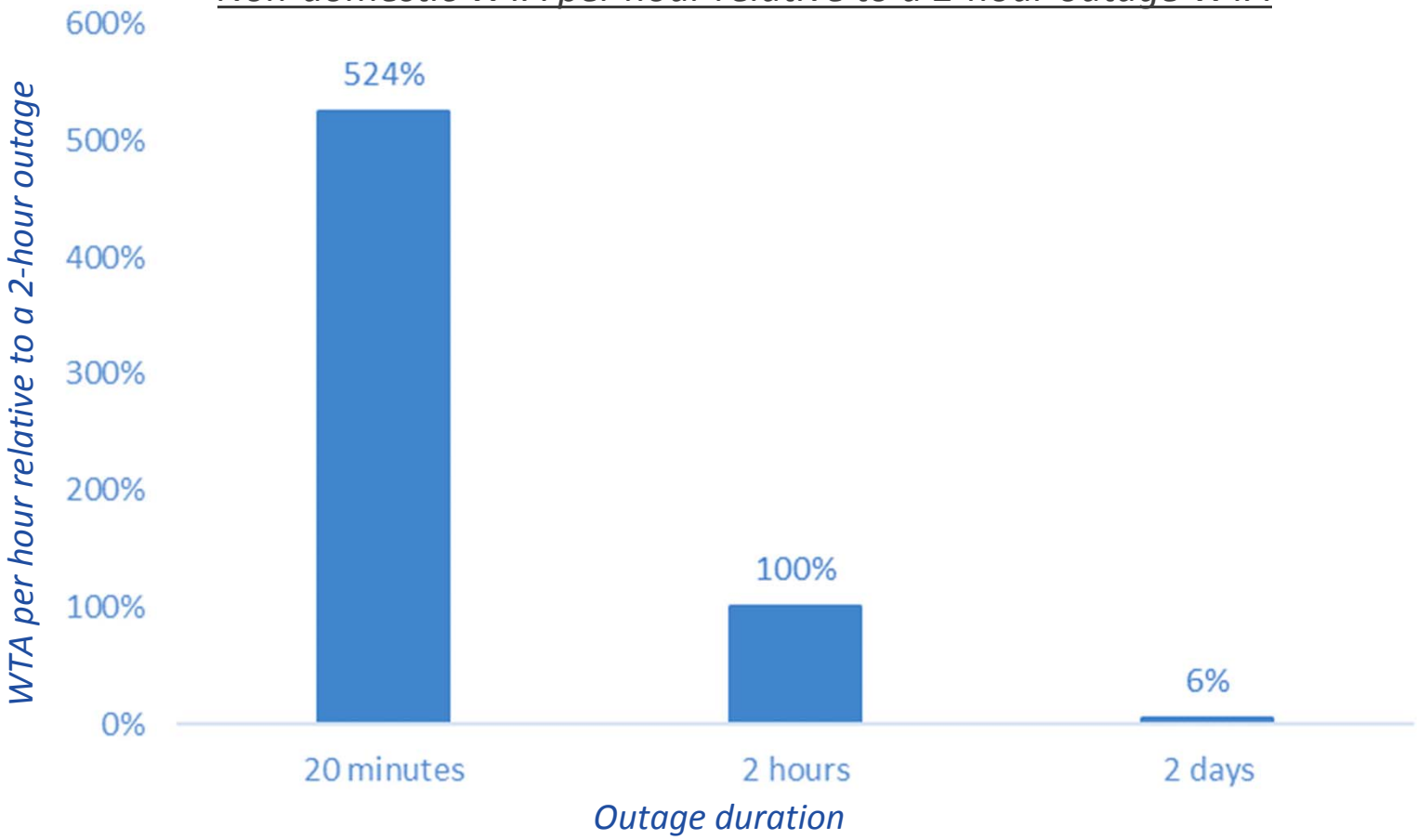


Notice is less beneficial when consumers ultimately face an outage of longer duration

Primary research draft findings

Impact of duration on WTA – Non-domestic

Non-domestic WTA per hour relative to a 2-hour outage WTA

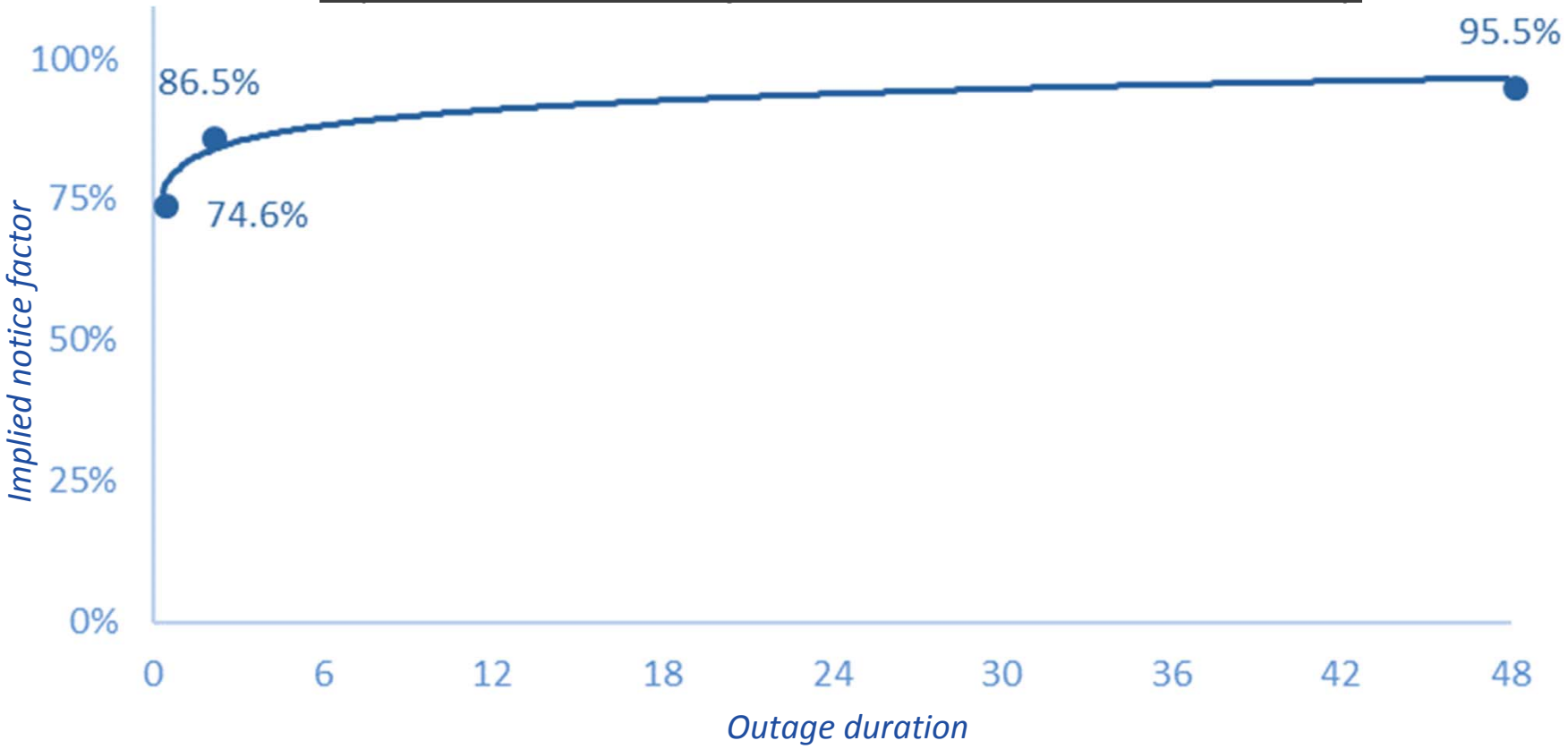


The decrease in marginal WTA is even more pronounced for non-domestic consumers

Primary research draft findings

Impact of notice (VoLA) – Non-domestic

Implied Industrial notice factor over time, non-domestic survey



Notice is less beneficial with increasing duration, but it is less beneficial for non-domestic than for domestic consumers

Recap

Advantages of our approach

• Consistent and objective application across Europe	☑
• Developed scientific evidence-base for assumptions and specific requirements using supporting research	☑
• Easily replicated	☑
• Can be readily built on through refinement of specific assumptions over time	☑
• Not dependent on occurrence of an outage (direct methods)	☑
• Not subject to subjectivity or cultural differences (stated preference)	☑
• Applicable within time and budget constraints	☑

Limitations

Production-function methodology

- Dependent on data availability and quality
- Dependent on key assumptions:
  - Labour theory assumption that hourly wage is equivalent to the marginal unit of leisure
  - Marginal lost hour of leisure equivalent to average lost hour of leisure
  - VoLL is driven primarily by direct effect of loss of leisure or GVA. More challenging to incorporate consideration of indirect effects such as damages
  - Value of leisure of employed individuals is used as a basis for leisure value of non-employed
- Considers a number of aggregated consumption sectors which may contain heterogeneous consumers
- Difficult to consider impact of additional factors including duration, notice and timing directly
- Can result in seemingly high VoLL estimates for consumers/sectors with small levels of consumption

Limitations

Production-function methodology – data limitations

Three data limitations were identified:

1. ***A mismatch between GVA and electricity consumption data***: Granularity of consumption data constrained our disaggregation of non-domestic consumers. However, the number of sectors included in our analysis is at the upper bound of previous literature.
2. ***Missing data points:*** There were a number of missing data points that we needed to fill using assumptions. These were mostly limited to Malta and Luxembourg.
3. ***Lack of EU hourly load data at a disaggregated consumer level***: Our TSD analysis therefore assumed that demand factors were primarily driven by domestic consumers. We used a case study using data for Great Britain to test this assumption.

Limitations

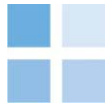
Primary research

- Our survey was designed to elicit ***relative*** considerations, e.g. of the impact of duration and the provision of notice on VoLL. It was not designed to identify an absolute measure of VoLL.
- The survey was designed to maximise benefits within budget and time constraints.
- Within this narrow scope, we believe that the impact of these limitations was small.
- However, we do note the following limitations:

Limitation	Potential impact on results
Web-based survey	Sample bias
Survey in English only	Sample bias
Approach to promoting responses (through NRAs and direct channels)	Sample bias Strategic responses
Use of WTA, contingent valuation	Limited scope for estimation of VoLL
Lack of incentive for honest responses	Limited scope for estimation of VoLL Strategic responses
Sample size	Prevents detailed analysis with statistical significance

4 DRAFT FINDINGS

Draft findings



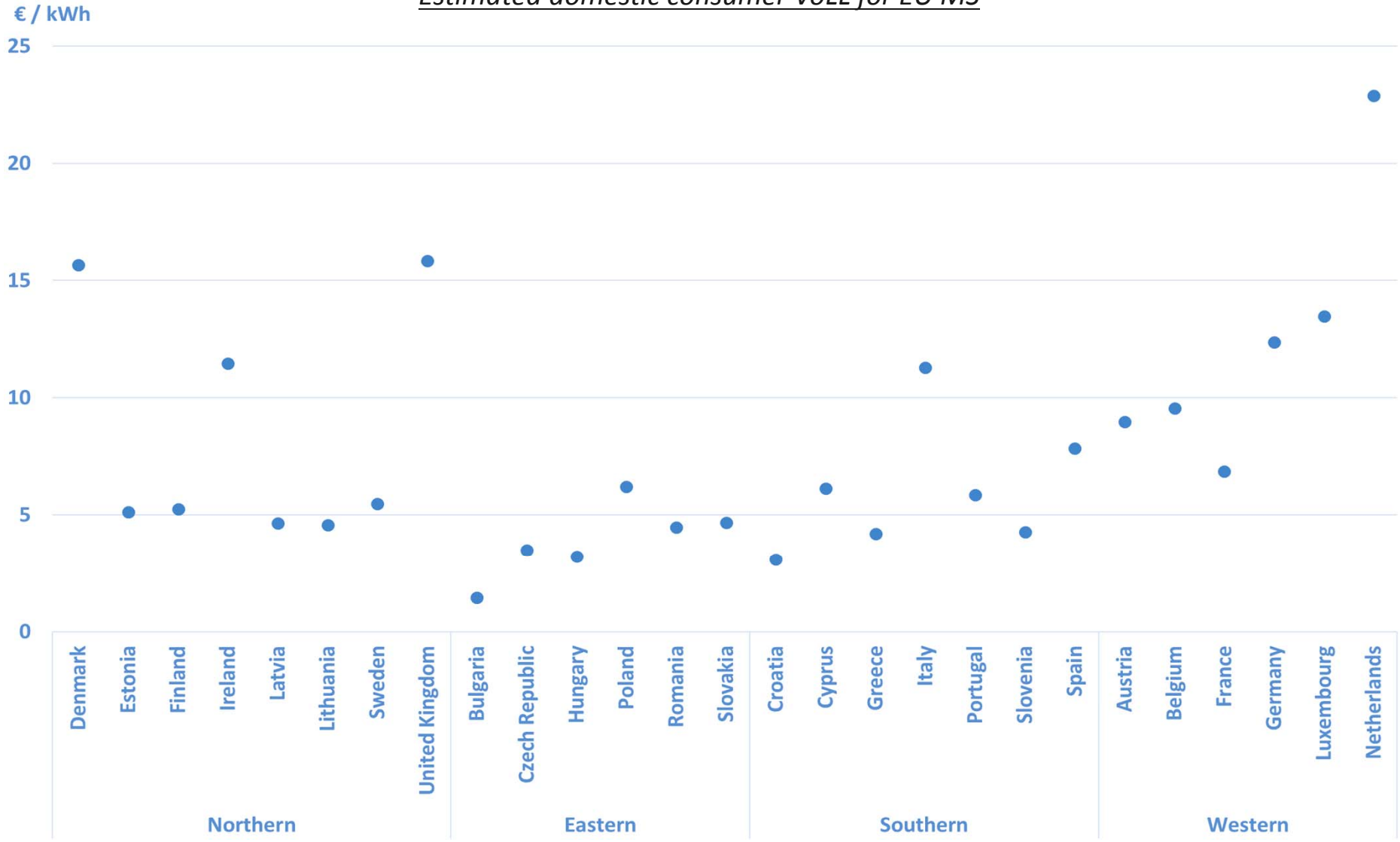
What we will discuss

- Domestic VoLL estimates
  - Regional differentiation
- Non-domestic VoLL estimates
  - Differentiation by consumer type
  - Consideration of Industrial and Services sector
- Time-specific dependence analysis

Draft Findings

VoLL estimates by region - Domestic

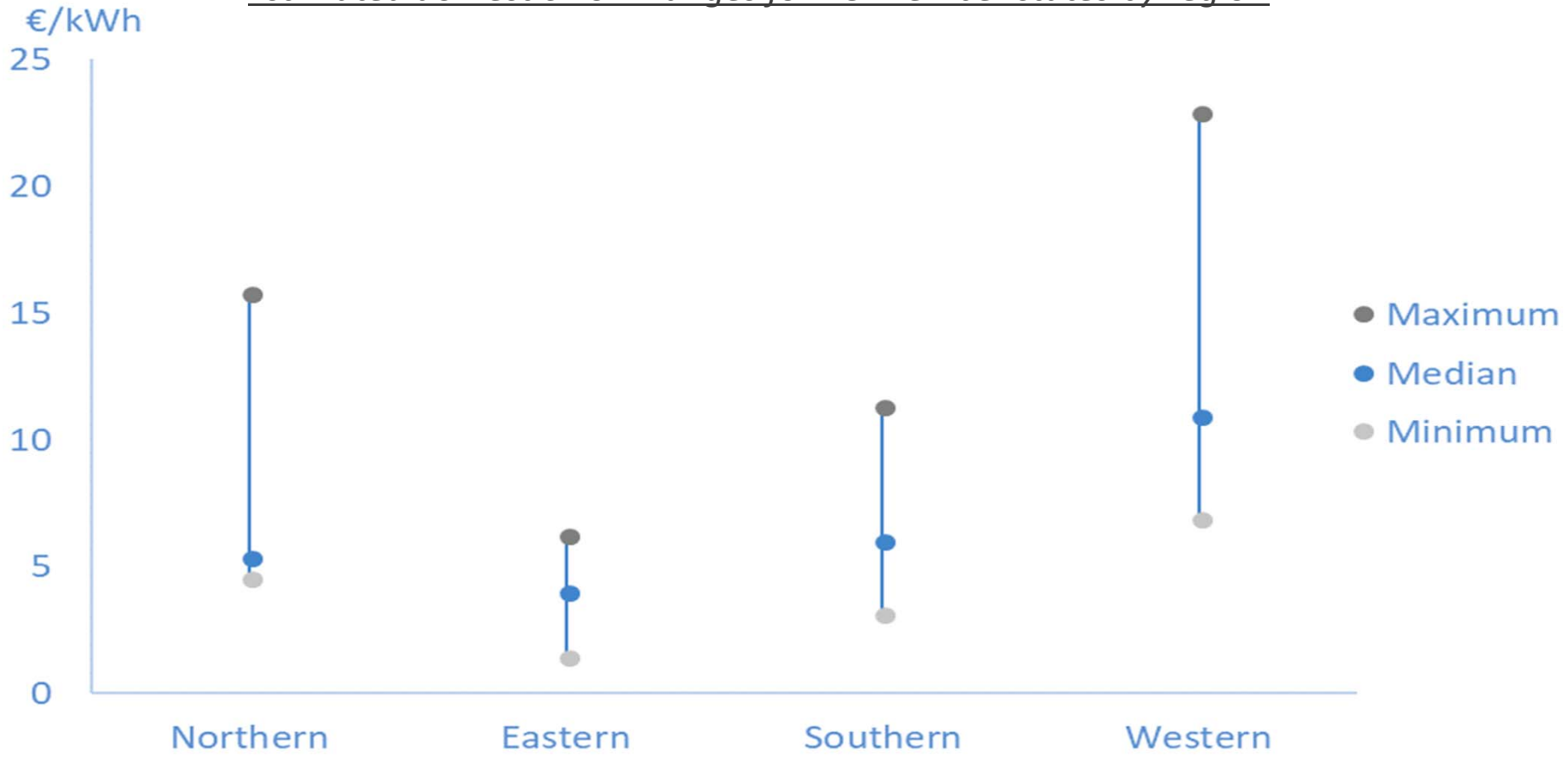
Estimated domestic consumer VoLL for EU MS



Draft Findings

VoLL estimates by region - Domestic

Estimated domestic VoLL ranges for EU member states by region



VoLL estimates range from €1.50/kWh for Bulgaria to €22.94/kWh for the Netherlands

VoLL generally higher for more northern MS with higher income levels

Draft Findings

Comparison of domestic VoLL against a sample of national studies (2015 €)

Member State	Study	Year	CEPA	Comparison
Austria	Reichl et al	2012	9.01 €/kWh	2.8 €/kWh
Cyprus	Zachariadis and Poullikkas	2012	6.19 €/kWh	9.78 €/kWh
Germany	Growitsch et al	2013	12.41 €/kWh	13.32 €/kWh
Italy	Bertazzi and Fumagalli	2005	11.34 €/kWh	12.69 €/kWh*
Republic of Ireland	Leahy and Tol	2010	11.52 €/kWh	24.7 €/kWh
Spain	Linares and Rey	2012	7.88 €/kWh	8.78 €/kWh
U.K.	London Economics	2013	15.90 €/kWh	8.93 – 15.17 €/kWh**

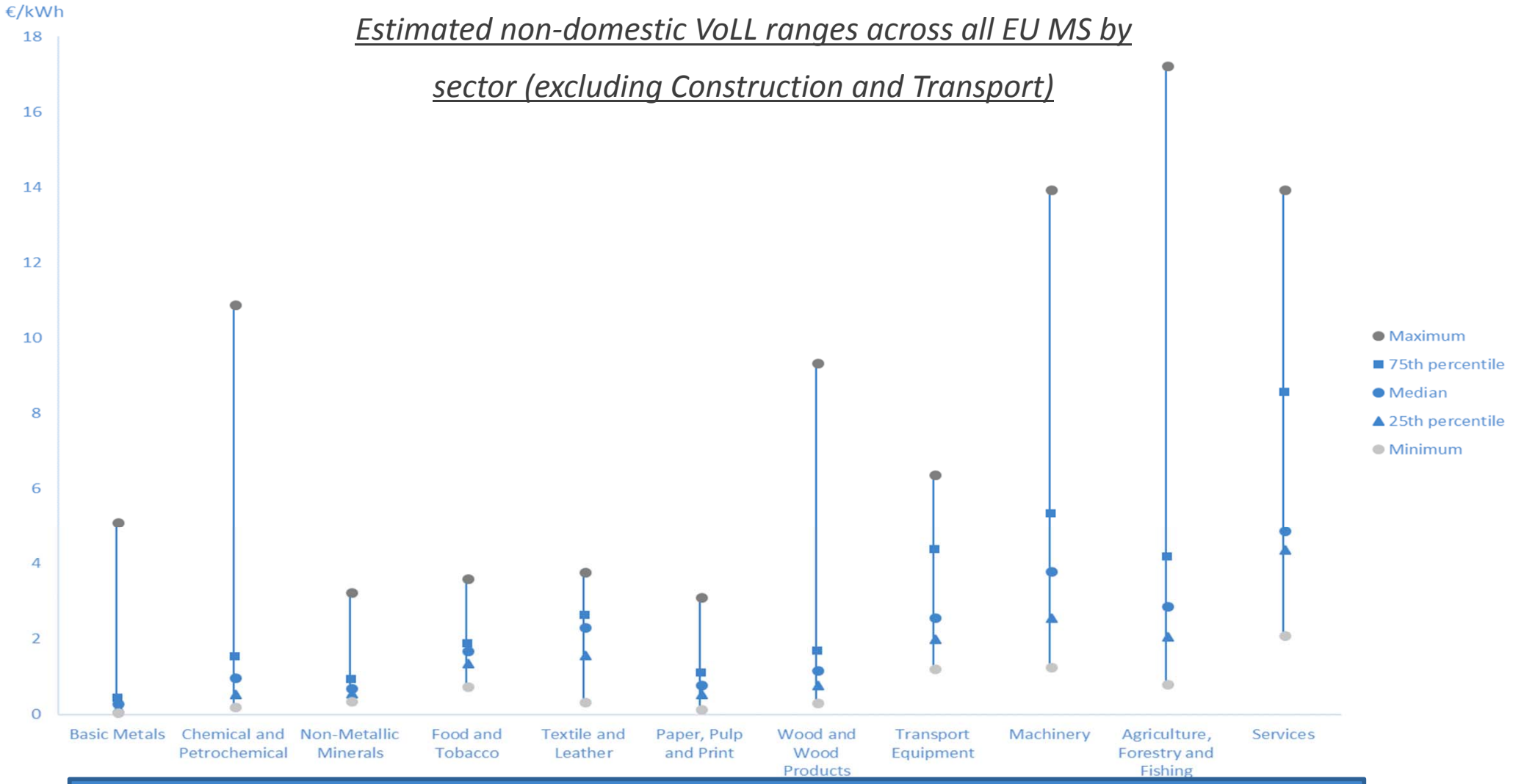
**NB: Bertazzi and Fumagalli identify a very broad range of VoLL estimates depending on whether WTP or WTA is used and depending on duration of the outage. The stated figure represents the average of the WTA and WTP estimates for a one hour outage as per the triangulation approach recommended by CEER.*

*** 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.*

Draft Findings

VoLL estimates by sector – Non-domestic

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

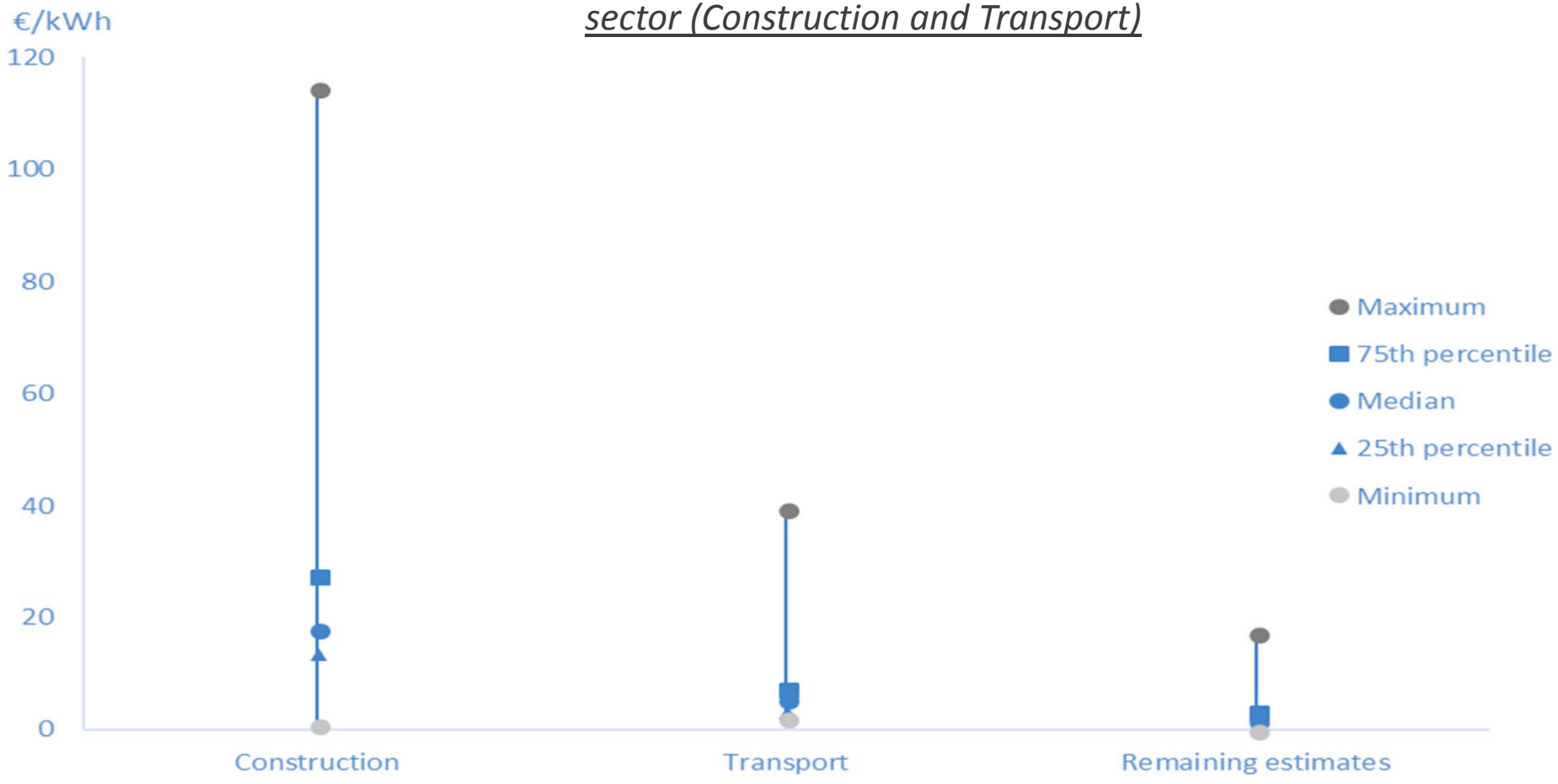


Some sectors demonstrate a relatively broad range of VoLL across the EU

Draft Findings

VoLL estimates by sector – Non-domestic (2)

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



Possible outliers seem particularly pronounced for Transport and Construction industries

Draft Findings

VoLL estimates by sector – Non-domestic (3)

We provide three hypotheses to rationalise outliers:

1. **VoLL is 'normalised' using consumption**:
   - VoLL is measured '*per unit of electricity consumed*'.
   - Hence, where a high level of output is produced using a low level of electricity, VoLL may reach very high levels.
   - However, intuition may expect VoLL to correlate with level of consumption.

2. **Assumptions in relation to 'criticality' of input**:
   - Our s.f. is designed to reflect the level of 'criticality' of input.
   - However, our research does not allow for very granular analysis of the s.f. of particular industries.
   - Hence, a lower s.f. for certain industries may lead to lower VoLL estimates.

3. **Data reporting**:
   - Inconsistencies in data reporting and sector definitions may lead to anomalies or may exacerbate those other hypotheses above.

Draft Findings

Comparison of Industry sector VoLL against a sample of national studies* (2015 €)

Member State	Comparison paper	Year	CEPA	Comparison**
Cyprus	Zachariadis and Poullikkas	2012	0.45 – 5.45 €/kWh	2.06 €/kWh
Germany	Growitsch et al	2013	0.41 – 6.09 €/kWh	1.81 €/kWh
Republic of Ireland	Leahy and Tol	2010	0.34 – 10.77 €/kWh	4 €/kWh
Spain	Linares and Rey	2012	0.28 – 4.76 €/kWh	1.49 €/kWh
UK	London Economics	2013	0.51 – 5.53 €/kWh	0.43 – 14.07 €/kWh***

**NB: We have excluded the Transport and Construction sectors from the ranges presented to align with that presented in national reports.*

***NB: Note that few studies consider Industrial consumers at the same level of disaggregation as measured in our study. Hence a broad range around the point of comparison is to be expected. Inconsistent definitions between studies warrant caution in comparison.*

**** Stated range is of disaggregated industrial sectors from both London Economics' 'capacity' and 'utilisation' methodology approaches*

Draft Findings

Comparison of Services sector VoLL against a sample of national studies (2015 €)

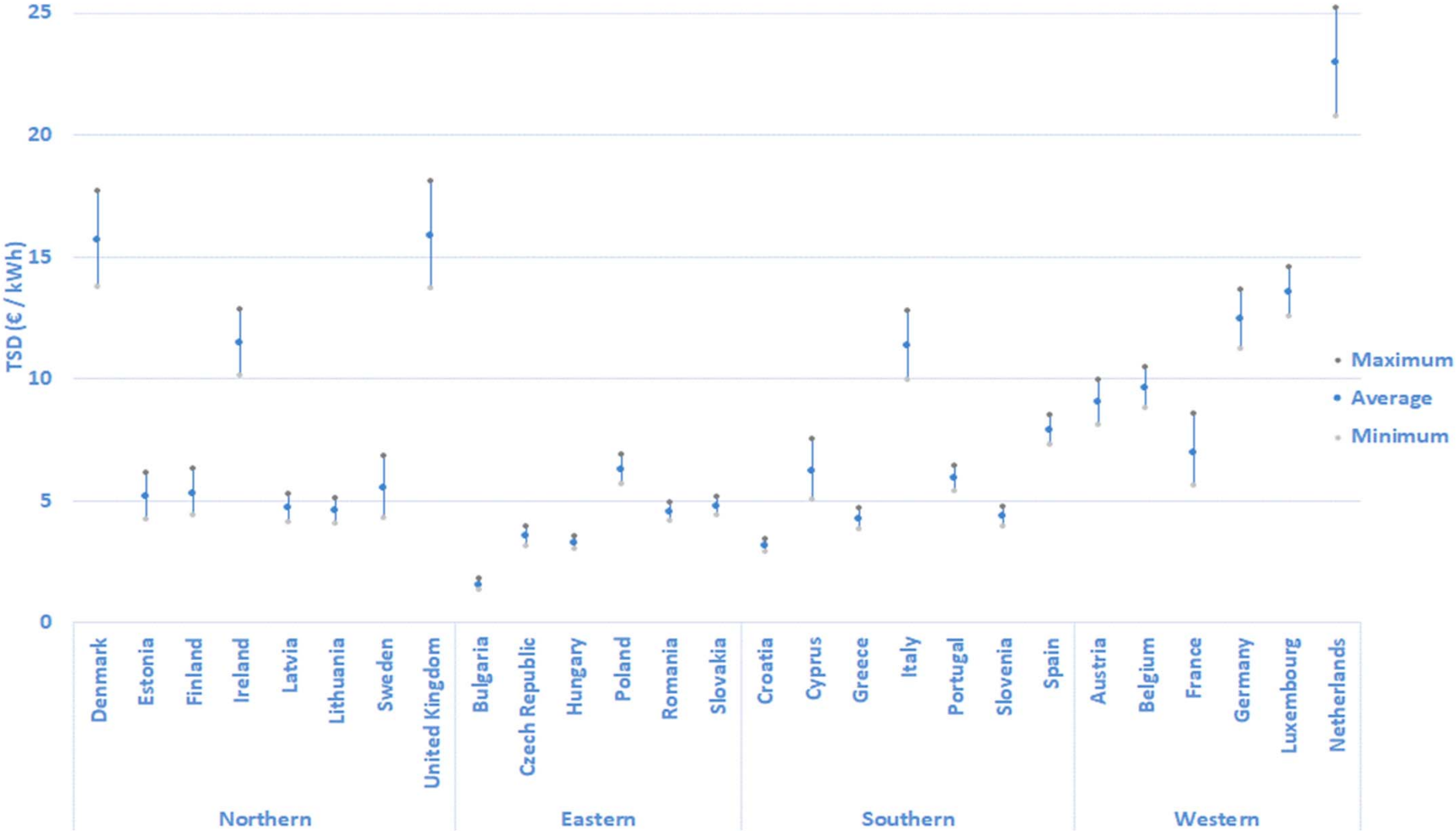
Member State	Comparison paper	Year	CEPA	Comparison	CEPA (100% s.f)
Cyprus	Zachariadis and Poullikkas	2012	4.65 €/kWh	6.60 €/kWh	6.81 €/kWh
Germany	Growitsch et al	2013	8.55 €/kWh	12.34 €/kWh	12.53 €/kWh
Republic of Ireland	Leahy and Tol	2010	13.97 €/kWh	13 - 14 €/kWh	20.48 €/kWh
Spain	Linares and Rey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

- Our headline VoLL estimates are generally about 2/3rds of that found in previous national studies.
- The difference can be explained by our application of an evidence-based substitutability factor for Services consumers.

Draft Findings

TSD analysis - Domestic

Domestic consumer TSD ranges for EU MS



5 CONCLUSIONS

Conclusions

Application of different areas of our analysis

Feature of our report	Applications
Pan-EU VoLL estimates	All applications – particularly those which apply cross-border
VoLL estimates by sector	National network planning; interruptions incentives and compensation Informing demand-side-response programmes Informing the order of disconnection
Impact of duration	System adequacy measures Procurement of balancing and back-up services Defining interruptions incentives and compensation
Impact of notice	Network planning (at all levels) Interruptions incentives and compensation Informing demand-side response programmes
Time-varying analysis	Network planning Cost benefit analyses Design of capacity markets Procurement of balancing and back-up services Interruptions incentives and compensation

Conclusions

Proposed areas for further research

Area of further work	Description
Granular analysis of s.f. and notice factors	More granular (e.g. at National level) would allow : • Validation of the findings of our research; • Granular refinement of assumptions – e.g. depending on type of consumer or nationality • Allow consideration of different notice periods (other than one day)
TSD analysis	Obtaining profiled consumption data with disaggregation by consumer type would allow more granular analysis of the TSD of different types of electricity consumers
Outlier analysis	More detailed analysis of consumers who represent outliers (e.g. the Construction industry) would allow the reasons for these results to be better understood
Analysis of disaggregated 'Services' sectors	Where available, disaggregated consumption data for Services consumers has allowed differentiation of this potentially heterogeneous consumer group. Gathering additional data would allow such estimates to be obtained across the EU

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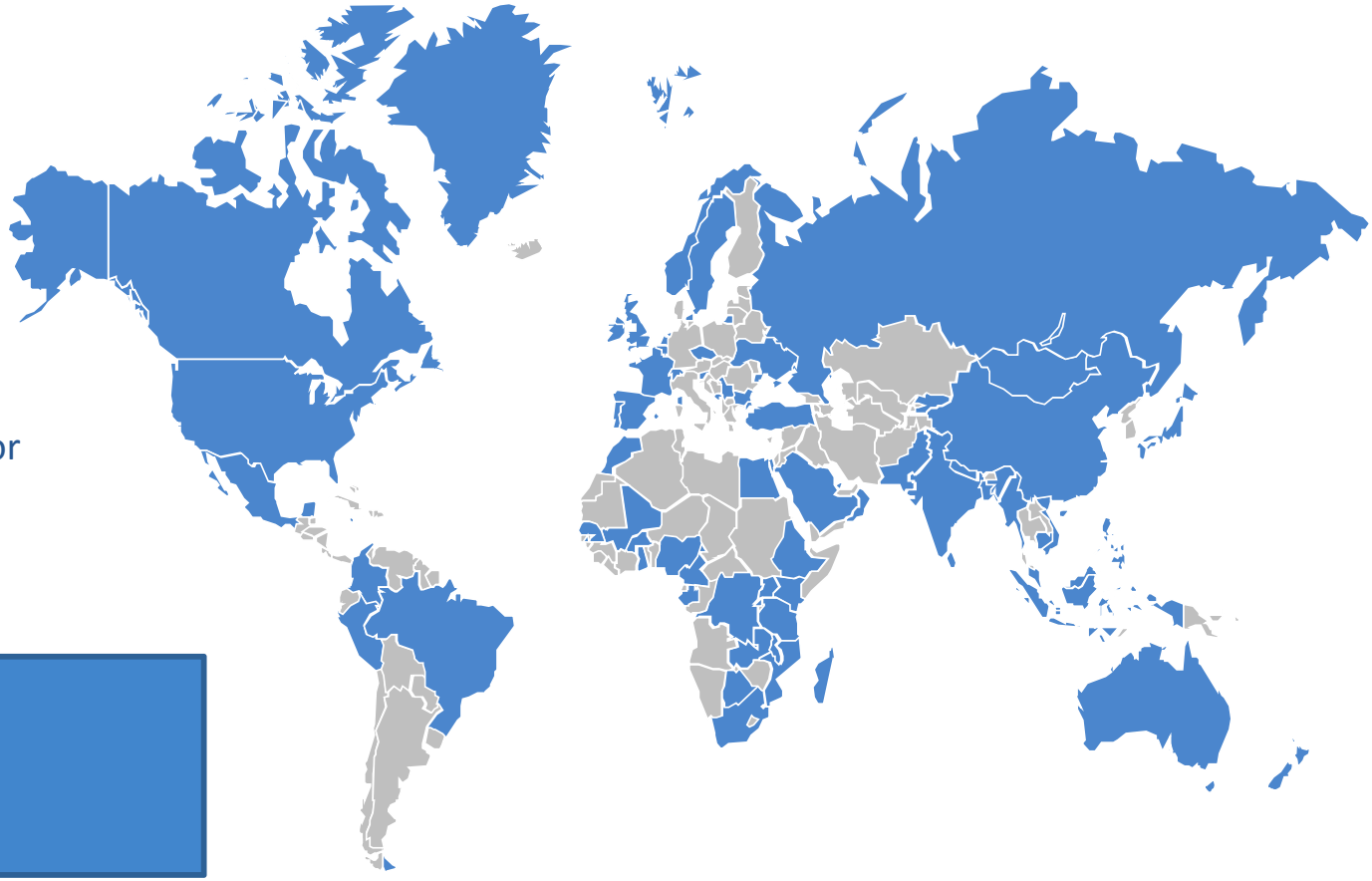

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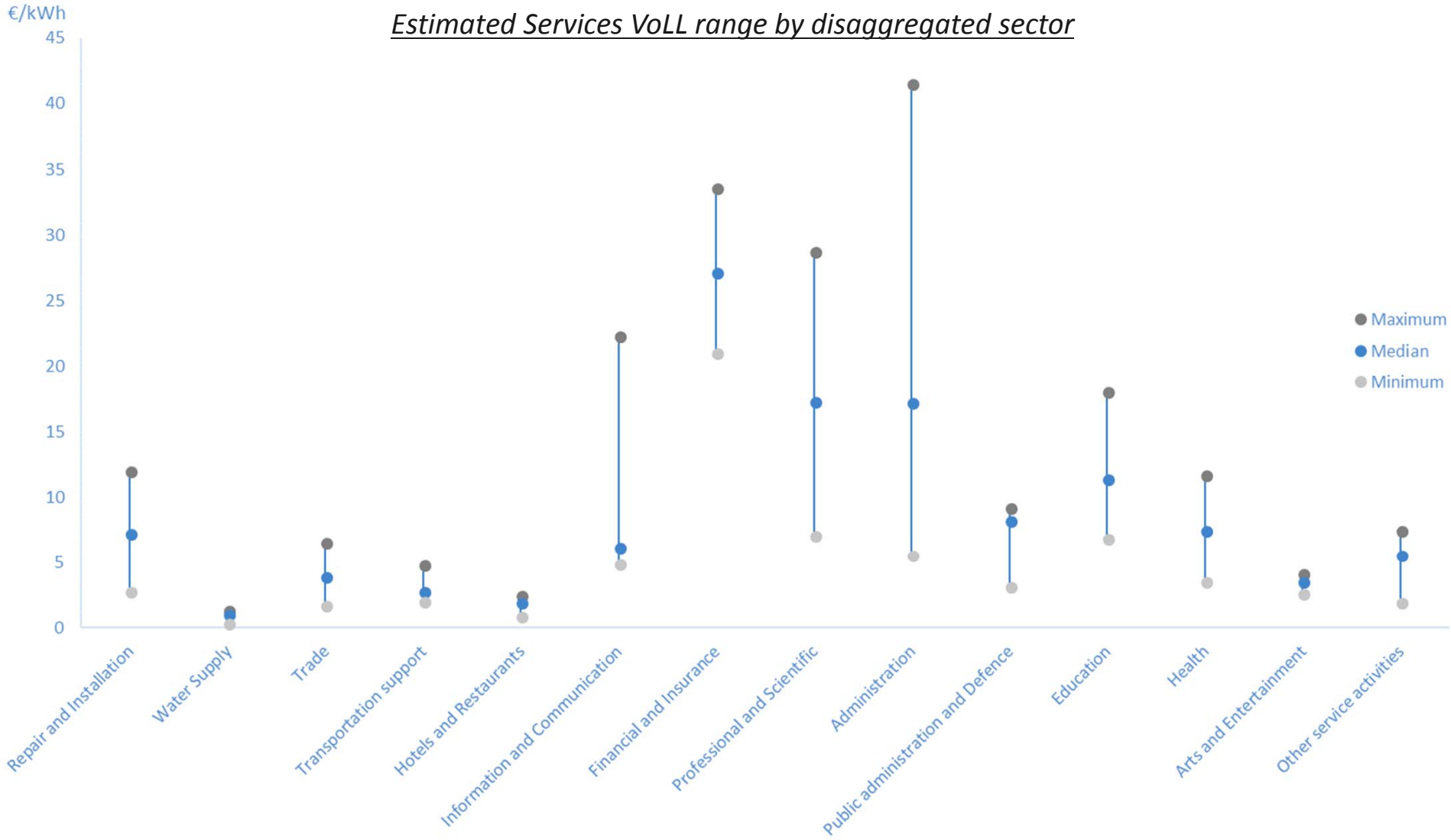
APPENDICES

A ADDITIONAL STUDIES AND SENSITIVITIES

Draft Findings

Disaggregated Services sector analysis (based on four MS only)

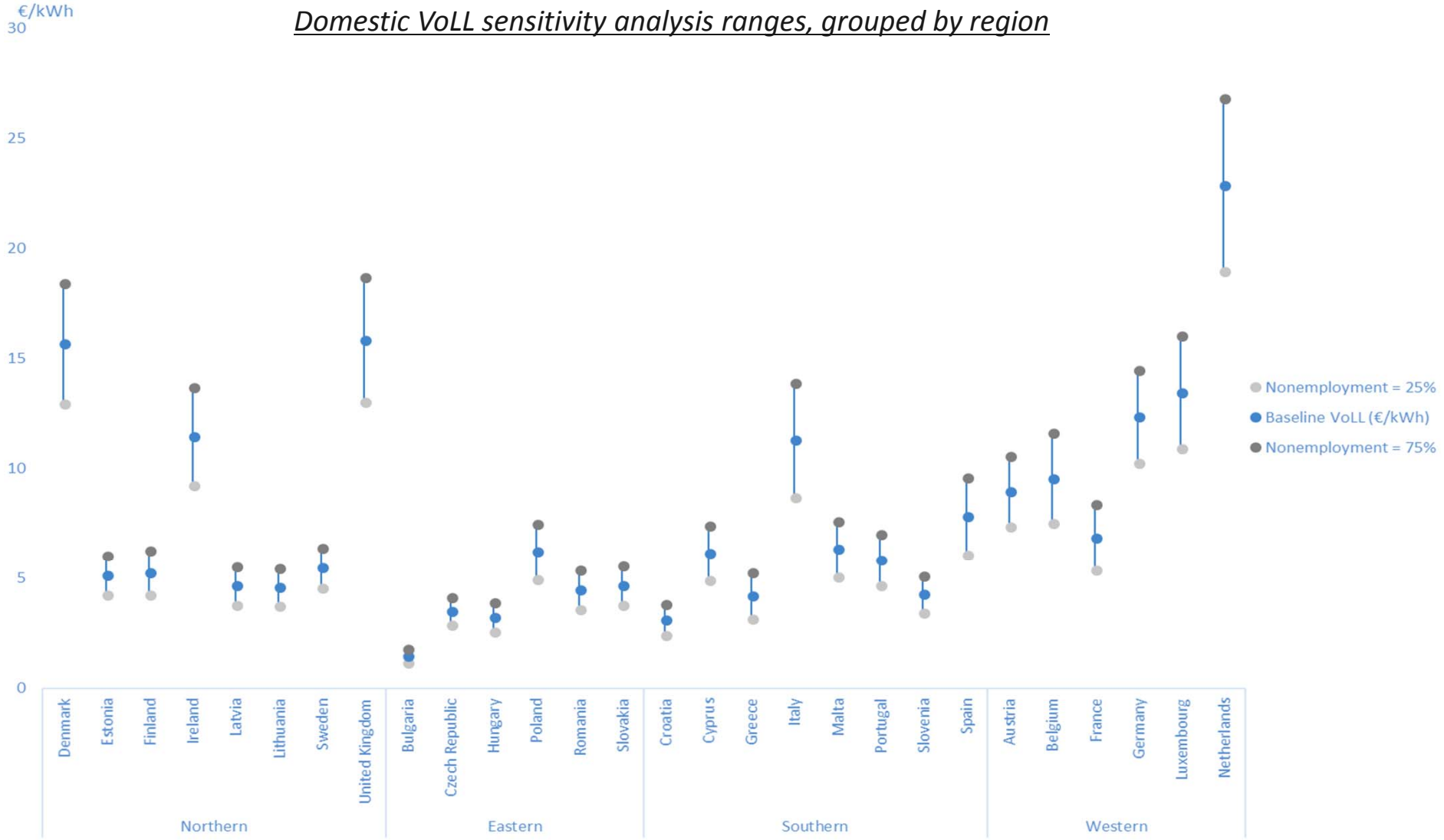
Estimated Services VoLL range by disaggregated sector



Draft Findings

Sensitivity analysis – Non-employment factor

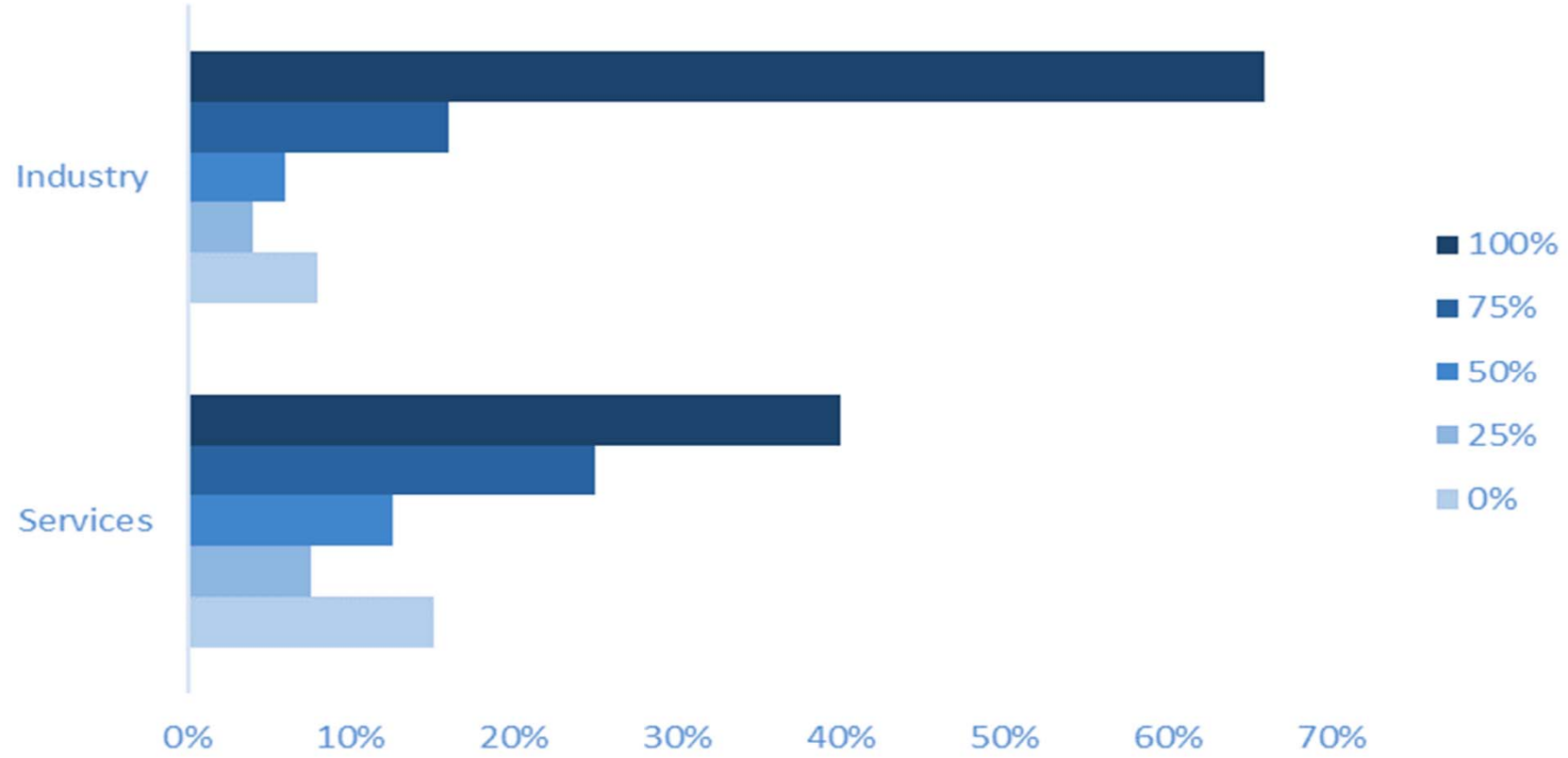
Domestic VoLL sensitivity analysis ranges, grouped by region



Assumptions

Sensitivity analysis – Industrial s.f. = 100%

Substitutability factor distribution, non-domestic survey



- Almost 70% of Industrial consumers state an s.f. of 100%
- We therefore analyse the impact of an s.f. of 100% for Industrial consumers as a sensitivity

Draft Findings

Sensitivity analysis – Industry sector s.f. = 100%*

Member State	Comparison paper	CEPA (80.9% s.f.)	CEPA (100% s.f.)	Comparison**
U.K.	London Economics	0.51 – 5.53 €/kWh	0.63 – 6.84 €/kWh	0.74 – 12.84 €/kWh
Republic of Ireland	Leahy and Tol	0.34 – 10.77 €/kWh	0.42 – 13.31 €/kWh	4 €/kWh
Germany	Growitsch et al	0.41 – 6.09 €/kWh	0.51 – 7.53 €/kWh	1.81 €/kWh
Spain	Linares and Rey	0.28 – 4.76 €/kWh	0.35 – 5.88 €/kWh	1.49 €/kWh
Cyprus	Zachariadis and Poullikkas	0.45 – 5.45 €/kWh	0.56 – 6.74 €/kWh	2.06 €/kWh

**NB: We have excluded the Transport and Construction sectors from these ranges to allow comparability with national estimates.*

***NB: Note that few studies consider Industrial consumers at the same level of disaggregation as measured in our study. Hence a broad range around the point of comparison is to be expected. Inconsistent definitions between studies warrant caution in comparison.*

Draft Findings

TSD: UK case study – Domestic and non-domestic demand factors

Domestic, Services and Industry UK demand factors

		UK (ENTSO-E)	Domestic	Services	Industry
Time of day	Day	110%	120%	130%	120%
	Night	90%	80%	70%	80%
Day of week	Weekday	106%	98%	127%	114%
	Saturday	102%	99%	94%	96%
	Sunday	92%	103%	79%	89%
Time of year	Spring	99%	97%	98%	98%
	Summer	87%	87%	91%	94%
	Autumn	100%	97%	94%	99%
	Winter	114%	119%	118%	110%

Provides support for EU 'seasonal' analysis. Some support for 'time of day' analysis. But does not support 'day of week' analysis

B DETAILED VOLL ESTIMATES

Draft VoLL estimates by Member State

Annual average VoLL (€/kWh) – Domestic

Austria	9.01
Belgium	9.60
Bulgaria	1.50
Croatia	3.15
Cyprus	6.19
Czech Republic	3.53
Denmark	15.73
Estonia	5.18
Finland	5.30
France	6.92

Germany	12.41
Greece	4.24
Hungary	3.27
Ireland	11.52
Italy	11.34
Latvia	4.71
Lithuania	4.62
Luxembourg	13.52
Malta	6.38
Netherlands	22.94

Poland	6.26
Portugal	5.89
Romania	4.52
Slovakia	4.73
Slovenia	4.32
Spain	7.88
Sweden	5.52
United Kingdom	15.90

Draft VoLL estimates by Member State

Annual average VoLA (€/kWh) – Domestic

Austria	5.00
Belgium	5.33
Bulgaria	0.83
Croatia	1.75
Cyprus	3.44
Czech Republic	1.96
Denmark	8.73
Estonia	2.87
Finland	2.94
France	3.84

Germany	6.89
Greece	2.35
Hungary	1.82
Ireland	6.39
Italy	6.29
Latvia	2.61
Lithuania	2.56
Luxembourg	7.51
Malta	3.54
Netherlands	12.73

Poland	3.47
Portugal	3.27
Romania	2.51
Slovakia	2.62
Slovenia	2.40
Spain	4.37
Sweden	3.06
United Kingdom	8.83

Draft VoLL estimates by Member State

Annual average VoLL (€/kWh) – Non-domestic

Member State	Basic metals	Chemicals and Petrochemicals	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

NB: The results for Mining and Quarrying did not pass our data verification procedures so have not been included.

Draft VoLL estimates by Member State

Annual average VoLL (€/kWh) – Non-domestic (2)

Member State	Basic metals	Chemicals and Petrochemicals	Non-metallic minerals	Food and Tobacco	Textile and Leather	Paper, pulp and print	Wood and Wood Products
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.

Draft VoLL estimates by Member State

Annual average VoLL (€/kWh) – Non-domestic (3)

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

*Unable to estimate VoLL due to limited data.

Draft VoLL estimates by Member State

Annual average VoLL (€/kWh) – Non-domestic (4)

Member State	Transport Equipment	Machinery	Construction	Transport	Agriculture, Forestry and Fishing	Services
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.

C PARAMETERS AND DATA SOURCES

Parameters

Data sources – Domestic consumers (1)

Variable	Source	Units	Comments
Hours worked	Eurostat	Average usual weekly hours for employed person	• Used to derive time spent on leisure activities per day.
Hours spent sleeping and on personal care	CEPA literature review; Eurostat	Hours per day	• Assumed 11 hours of each day is spent on sleeping and personal care.
Substitutability factor	CEPA primary research	%	
Population employed/ not employed	Eurostat	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	Gigawatt-hour (GWh)	

Parameters

Data sources – Domestic consumers (2)

Variable	Source	Units	Comments
Hourly domestic electricity consumption	ENTSO-E; ELEXON settlement data	Megawatts (MW)	• Hourly load data is available from ENTSO-E for total load. • Primary approach: We assume that the profile of electricity consumption is driven primarily by domestic consumers. • Secondary approach: We used 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. • 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 notice factor

Parameters

Data sources – Non-domestic consumers

Variable	Source	Units	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. • In limited cases where gaps existed, they were eliminated using National data or taking a similar MS as a proxy.
Annual electricity consumption by use	Eurostat [nrg_105a]	Gigawatt-hour (GWh)	• Final energy consumption is broken down in line with our consumer segmentation.
Hourly electricity consumption data by use/ industry	ELEXON settlement data	KWh	• We used representative profile classes to develop a case study of hourly consumption for the case of Great Britain, disaggregated by sector.
Substitutability factor and Notice factor	Primary research	%	• We used our primary research to explore the s.f. and notice factor.

D LITERATURE REVIEW SUMMARY OF LITERATURE

Summary of literature reviewed (1)

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

Summary of literature reviewed (2)

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

Summary of literature reviewed (3)

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)

E SURVEY QUESTIONS

Primary research questions

Domestic survey questions

1. Please state your country of residence
2. Please confirm the currency that you will use in this survey
3. Approximately what percentage of the enjoyment of your leisure time relies on electricity provided by the electricity grid?
4. Is the time when a loss of electricity supply would have the greatest impact on your enjoyment of leisure...
   In summer / In winter / No difference
5. In the season you have selected above, is the time when a loss of electricity supply would have the greatest impact on your enjoyment of leisure...
   On a weekday (Monday – Friday) / At the weekend (Saturday or Sunday) / No difference
6. In the season and on the days you have selected above, is the time when a loss of electricity supply would have the greatest impact on your enjoyment of leisure...
   In the morning (06:00 – 10:00) / During the day (10:00 – 17:00) / In the evening (17:00 – 23:00) / At night (23:00 – 06:00) / No difference
7. Imagine that you will have no access to electricity supply from the grid for one **20-minute period and that no notice will be provided** ahead of the interruption. How much would you need to be paid to accept this scenario?
8. [As Q7, but for] one 2-hour period
9. [As Q7, but for] one 2 day period
10. Imagine that you will have no access to electricity supply from the grid for one **20-minute period and that 24 hours of notice will be provided** ahead of the interruption. How much would you need to be paid to accept this scenario?
11. [As Q10, but for] one 2-hour period
12. [As Q10, but for] one 2 day period
13. Which of the following categories best describes your employment status?
    Employed, working full-time / Employed, working part-time / Not employed, looking for work / In education / Not employed or in education, NOT looking for work / Retired / Disabled, not able to work / Prefer not to say
14. Please estimate your annual household income (after tax and any other deductions)
    €0 - €10,000 / €10,000 - €25,000 / €25,000 - €50,000 / €50,000 - €75,000 / €75,000 or more / Prefer not to say

Primary research questions

Non-domestic survey questions (1)

1. Please state the name of your company (Optional)
2. Please name the country in which your company is based. If located in multiple countries, please name the country in which the majority of your business activity takes place or where you are personally most active or best placed to respond.
3. Which of the following best represents the area in which your business is active?
   [Sectors, segmented as described previously] / Other (please specify)
4. Is your company a small and medium-sized enterprise (SME)? (This is defined as a company which employs fewer than 250 people and has an annual turnover of less than €5 million)
5. Approximately how much do you pay for electricity provided from the electricity grid each year? (i.e. what is your approximate annual electricity bill)? Please estimate your annual bill in euro (€)
6. Approximately what percentage of the output (or services) of your company could be continued in the event of a loss of supply from the electricity grid for 2-4 hours? When responding, please take into account any equipment/devices that can shift from grid power to battery power and thus could continue to be used without electricity from the grid. Please also consider any on-site generation capability that you may have available.
7. Approximately what percentage of this lost productive output (or services could be prevented without significant cost if you were given 24 hours notice ahead of the loss of supply? For example, you may be able to shift productive activities by re-timing your operations, by notifying workers of a change to shift patterns or by re-scheduling maintenance/downtime.
8. Is the time when a loss of electricity supply would have the greatest impact on the output of your business...
   In summer / In winter / No difference
9. In the season you have selected above, is the time when a loss of electricity supply would have the greatest impact on the output of your business.....
   On a weekday (Monday – Friday) / At the weekend (Saturday or Sunday) / No difference
10. In the season, and on the days you have selected above, is the time when a loss of electricity supply would have the greatest impact on the output of your business.....
    In the morning (06:00 – 10:00) / During the day (10:00 – 17:00) / In the evening (17:00 – 23:00) / At night (23:00 – 06:00) / No difference

Primary research questions

Non-domestic survey questions (2)

8. Imagine that you will have no access to electricity supply from the grid for one **20-minute period and that no notice** will be provided ahead of the interruption. What percentage of your monthly bill would you need to be refunded to accept this scenario?
9. [As Q7, but for] one 2-hour period
10. [As Q7, but for] one 2 day period
11. Imagine that you will have no access to electricity supply from the grid for **one 20-minute period and that 24 hours of notice** will be provided ahead of the interruption. What percentage of your monthly bill would you need to be refunded to accept this scenario?
12. [As Q10, but for] one 2-hour period
13. [As Q10, but for] one 2 day period

F SECTOR MAPPING

Non-domestic sector mapping (1)

Electricity consumption and GVA data available at EU level informed our mapping

Mapping no.	Electricity consumption	GVA
1	Iron and Steel Non-ferrous Metals	Manufacture of basic 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

Non-domestic sector mapping (2)

Electricity consumption and GVA data available at EU level informed our mapping

Mapping no.	Electricity consumption	GVA
11	Transport	Transportation and storage
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

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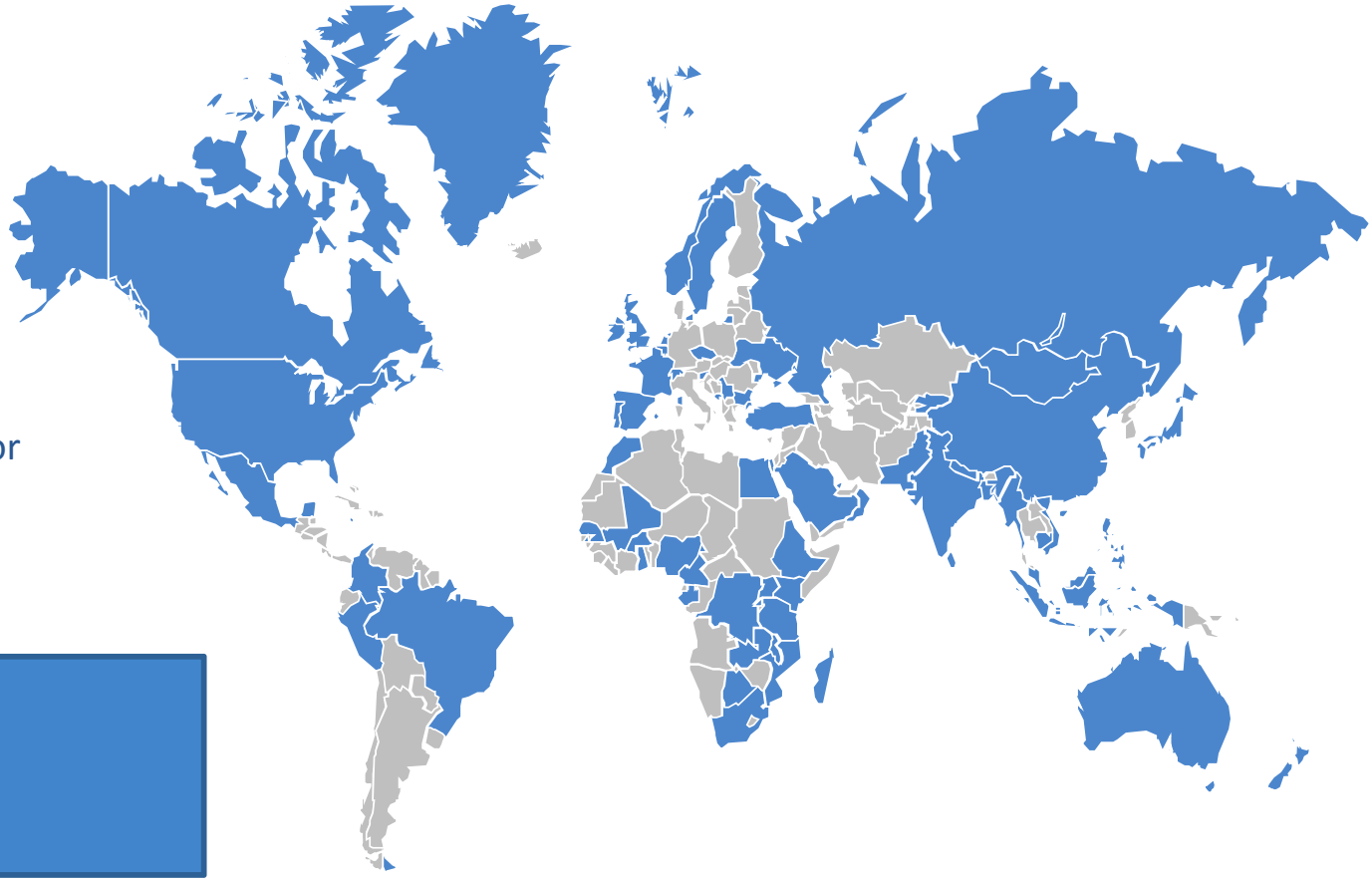

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