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Societal appreciation of energy security

Volume 1: Value of lost load – households (EE, NL and PT)

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Societal appreciation of energy security. Volume 1: Value of lost load – households (EE, NL and PT)

The report presents the results of a multi-country survey providing qualitative and quantitative information on the Value of Lost Load, an indicator of the economic value of unserved energy during electricity outages (blackouts). The point of view of residential consumers in the electricity market is explored through a discrete choice experiment. The results, in-line with other studies in this framework, highlight that respondents are willing to support further increases in the reliability and quality of electricity supply. Furthermore, consumers are found to have as aversion toward the possibility of losing their current security. Using a random parameter logit, we show that the ways to perceive the losses of security are remarkably dispersed. The survey was conducted in Estonia, the Netherlands and Portugal.

Contents

Foreword

This report was developed in the framework of the joint DG Energy – Joint Research Centre project entitled *Societal Appreciation of Security of Energy Supply (SASOS).*

Publications in the series *Societal appreciation of energy security:*

- Volume 1: Value of lost load – households (EE, NL and PT)
- Volume 2: Long-term security (EE, NL and PT)
- Volume 3: Non-residential actors (EE, NL and PT)
- Volume 4: Value of Lost Load - Greece

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Executive summary

The Value of Lost Load (VoLL) is an indicator of the economic value that consumers place on the energy not served in case of a supply disruption, e.g. an electricity outage (blackout). VoLL is extensively used by industry and regulators for benchmarking the operating conditions of an energy system. For example, the perceived worth of the reliability of the energy system can be used to assess infrastructure investments for improving supply reliability. This report presents estimates of the VoLL of electricity supply for households in three countries: Estonia, the Netherlands and Portugal. These three EU member states enjoy different levels of security of energy supply, which can be characterised as (relatively) high for the Netherlands, medium for Portugal, and low for Estonia.

The authors designed and conducted two surveys covering different aspects related to security of energy supply, and applied comparable econometric analyses. A sample of households assessed scenarios of a blackout through a discrete choice experiment (DCE). This report illustrates the methodologies incorporated for the DCE and the subsequent results. In particular, we estimated in monetary terms the households' willingness-to-accept (WTA) a larger number or longer lasting power cuts and the relevant compensation required, as well as their willingness-to-pay (WTP) to avoid such outages.

Policy context

The results can inform the ex-ante evaluations of infrastructural investments aimed at modernizing the electricity grids, and when designing (re-)electricity markets, e.g. to set price caps in spot markets and other regulatory measures.

Key conclusions

The analysis of the survey data unveils an asymmetry in the perception of gains and losses regarding the quality of electricity supply. In particular, the amount energy users would pay for securing an increase in quality of supply of electricity (fewer blackouts) is lower than the compensation they require for accepting a symmetric decrease in quality (more blackouts). This confirms results of other empirical studies, indicating that energy users already feel entitled to the current (high) level of quality. A psychological mechanism of aversion to losses is also well explained by the prospect theory of Kahneman and Tversky (1979).

In this exercise we explicitly modelled the changes in utility associated with either higher or lower levels of power outages with respect to the baseline of the status quo using discrete choice experiments (DCE). In particular, one DCE estimates the WTP for investments improving the continuity of supply, and a second the WTA compensation for a deterioration of electricity supply in terms of outages.

The WTP for improving of electricity supply continuity by 1 kilowatt-hour (kWh) is found to be €0.66 in Estonia, €1.03 in the Netherlands, and €1.17 in Portugal. These values capture directly the way consumers are pricing the benefits of improving the quality of the service.

The experiment on WTA elicits the minimum compensation the consumer accepts for the inconveniences from additional blackouts with respect to the baseline of the current continuity of electricity supply. This provides values that are substantially higher than the previous ones. These values are more representative of the damage the residential consumers would suffer in case of a decline of the quality of supply. The compensation required for an increase of 1 kWh of unserved energy is found to be €17 in Estonia, €24.51 in the Netherlands and €15.22 in Portugal. The use of a Random Parameter Logit model allowed to see how the preferences in terms of WTP are much more dispersed, giving evidence of a notable heterogeneity in the way consumers consider the importance of continuity of electricity supply. The values mentioned above are referred to unexpected (unplanned) power outages. The study also provides monetary values for the case of planned outages.

Main findings

The study offers monetary evaluations that can be applied for policy support uses, both for the ex-ante analyses of the feasibility of measures increasing the reliability of power grids, and for the evaluation of damages from blackouts.

Related and future JRC work

This report focuses on the appreciation of security of supply in the short term; while a forthcoming (volume 2) will focus on the long-term energy security. Another report (volume 3) will compare the households' preferences and points-of-view emerging from the first two volumes with a consistent set of preferences expressed by other actors involved in the Estonian, Dutch and Portuguese electricity markets: distribution system operators, electricity producers, industrial and commercial customers. In particular, it will analyse whether the different actors converge in considering specific components of the concept of energy security, and offer insights on consumers' attitudes and values.

A further report (volume 4) will be dedicated to a survey conducted in Greece, embedding many of the aspects of the previous volumes, for both residential and non-residential consumers.

1 The Value of Lost Load

The main scope of this study is to investigate the value that consumers place on the comfort of having a continuous supply of electricity for residential uses. Monetizing this value of continuity allows informing policy choices, such as cost-benefit analyses for investments to modernise electricity grids. Today, the quality of electricity supply is high in most EU member states, but rapid changes in the structure of electricity supply and demand are likely to increase the cost of maintaining the current levels of reliability. For example, the expected higher penetration of intermittent renewable sources, distributed generation and electric mobility will necessitate require a reshaping of traditional grids.

A cost-benefit approach for choosing an optimal level of security suggests adopting the level of security of electricity supply which equalizes the benefits of marginally reducing blackouts with the financial costs necessary to achieve such reductions.

In the relevant literature there is no clear consensus on how consumers will respond to changes in the level of continuity of the electricity supply, and investments in physical infrastructures require an explicit assessment of the social needs with regards to such intangible aspects. The Energy Union, which is the current energy strategy of the EU, envisages the protection of consumers' prerogatives (especially for vulnerable categories) and a more active involvement for residential energy users in retail markets. Examples of this shift from a passive to a more direct involvement of final consumers include spot pricing which allow energy users to respond to shortages in electricity supply by reacting to price signals, interruptible contracts where final users actively provide flexibility to the system accepting reductions of served capacity, and other mechanisms.

The socio-economic approach adopted in this study evaluates to which extent the consumer appreciates the protection from losses of energy services. The appreciation of short term electricity security of supply by residential consumers is represented by the Value of Lost Load (VoLL), a monetary indicator. In particular, VoLL is defined as the perceived value of unserved electricity for final consumers. In other words, it represents the perceived 'cost of outages'.

The (perceived) damage from a blackout is usually dependent on its duration (euros/minutes of supply lost), described by the Customer Damage Function (CDF) (Billinton, et al., 2001). If the unmet demand is explicitly taken into account, it is possible to normalize the outage costs obtained from the CDF expressing the worth of reliability as a cost per unit of energy. The VoLL is such a metric, quantifying the worth consumers assign to the unit of energy unserved, that is, a proxy of the value of the energy services lost from the outage.

The applications of cost-benefit analyses for investments improving power grids are one of the areas where the VoLL can have an important role. Figure 2 provides examples of input data that can enter into a costs-benefit exercise within this framework. One case is the massive blackout in North-eastern US and Canada (14-15 August 2003) which triggered a debate over the needs of improving the reliability of the power systems. Estimates of investment costs provided by industry were in the range of $50-100 billion and compared to the benefits of the potential improvements in reliability. Outage costs of "reliability events" to US consumers were also analysed by (LaCommare & Eto, 2006) who used an economic assessment of the overall damage to compare investment costs for the new power lines with the benefits of avoiding the consequences of poor reliability of the grid.

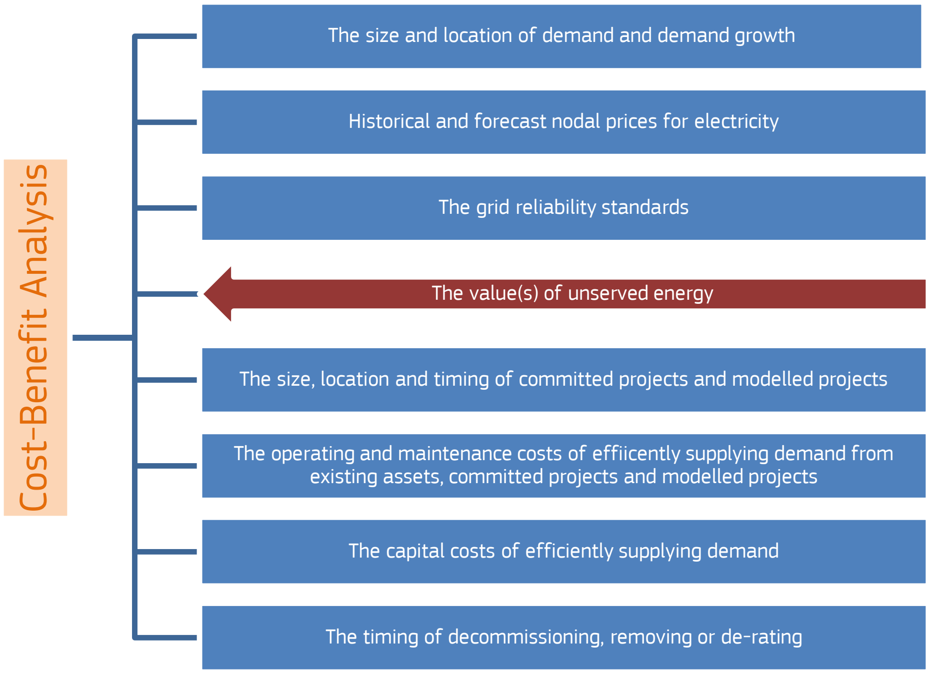
The VoLL is also a useful concept when designing energy markets, as it enables the economic evaluation of measures for both the security and the quality of electricity distribution. The value that consumers assign to supply security is represented by the value of the avoided damage of power cuts, thus, the VoLL can be used to define regulatory caps on electricity spot prices. This sort of "maximum clearing price" represents the highest willingness-to-pay (WTP) for energy under a situation of extreme scarcity of electricity. In fact, there could be the case where spot prices may be above the VoLL (e.g. due to excess demand), thus, final consumers would be paying a higher amount than the value of the damage that they suffer. A regulatory cap, estimated using the VoLL, would prevent the market to create such undesirable outcomes, i.e. high consumer expenditures and windfall profits for suppliers generated by contingencies of scarcity.

This report provides an evaluation of the VoLL based on stated preferences of residential customers collected through a survey involving households in Estonia (EE), the Netherlands (NL) and Portugal (PT). The analysis includes socio-economic factors beyond income that define the VoLL. These non-income factors have been largely unexplored in the existing literature.

In particular, the main novelty of this study regards identifying whether preferences over security are associated to individual characteristics of the energy user, including both *general* beliefs and behavioural elements and *specific* perceptions focused on the theme of energy security, including:

- personal and family habits in the use of energy technologies (the dependence from electricity and the level of gravity of inconveniences perceived in case of interruption of supply),
- attitudes toward the adoption of new habits in the way electricity is consumed, and
- information on personal values and attitudes (how the individual perceives herself/himself), the adherence to consumption behaviours more oriented to obtain comfort, or rather driven by ecological and green consumption behaviours

Figure 1. VoLL as a cost-benefit analyses factor for investments in power grids



Source: (Transmission Advisory Group & Electricity Commission, 2008)

The major work of econometric analysis and experimental design to estimate the VoLL from a Discrete Choice Experiment (DCE) was carried out by Alberto Longo. The survey questionnaire was co-developed by all contributors (Annex A), and the fieldwork was performed by SSI S.A. (Annex B).

The content of the report is organized as follows: Section 2 offers an overview of the main literature and applications of the VoLL in the EU context. Primary studies have provided original estimates for the VoLL in different contexts, approaches and techniques. As there is no standard applied universally, but rather a multitude of exercises tailored ad-hoc on specific cases, in the section we identify the main VoLL evaluation methods adopted by researchers and practitioners.

Section 3 focuses on the methodology chosen for this study, illustrating the stated preference approach through discrete choice experiments (DCE). The section presents the main elements of the surveys used to collect the data. In the survey, households were asked to value potential changes to the level of security of supply relatively to their *experienced* level of reliability, assessing the importance of the damage that they would suffer in case of interruption of energy supply. For this task, the DCE implemented focuses on the supply of electricity. Households are confronted with hypothetical scenarios of changes on the continuity of electricity supply and provide, through the experiment, estimates of their WTP to secure increased continuity (fewer blackouts) and estimates of their willingness-to-accept (WTA) a compensation for suffering potential reductions in the continuity (more blackouts). Section 4 illustrates and discusses the results of the DCE.

2 Methods and values for the VoLL

Power supply disruptions can create damages affecting to the vast majority of societal actors, especially given the ubiquitous use of electricity in modern societies. These damages are related to the duration of the blackout. In cases of very prolonged events e.g. due to catastrophes, the time span of the blackout may cause major problems to road lighting, treatment of waste water, health care facilities, supply chains etc. However, such exceptional conditions are beyond the scope of the present work, but the reader can refer to (Wenzel & Wolf, 2013). The methods and values reported in this section refer to blackouts that last less than a day.

Methodologies offered by the literature differ substantially depending on whether they target firms or households to assess the VoLL. The former case relies mostly on the assessment of losses in production, while discomfort and inconveniences are the central concept targeted by evaluations concerning households.

The classification of methods offered by Sullivan and Keane (Sullivan & Keane, 1995) is based on the source of information for the evaluation process and is built over three types: macroeconomic indicators, market based, and survey based assessments. Other proposed taxonomies are shown in Table 1, while a classification of the main types of damages is presented in (Billinton, et al., 2001).

Table 1: Classifications of VoLL methods in the literature

Authors	(Sullivan & Keane, 1995)	(Woo & Pupp, 1992)	(Billinton, et al., 2001)	(van der Welle & van der Zwaan , 2007)
Methods	Macroeconomic indicators (production function approach)	Proxy methods (production function approach)	Indirect analytical evaluations	Proxy methods (production function approach)
	Market based (market behaviour)	Market based (market behaviour)		Revealed preferences (market behaviour)
	Survey based	Contingent valuation	Customer surveys	Stated preferences (consumer surveys)
			Case studies (past blackouts)	Case studies (past blackouts)

Source: own compilation

In terms of order of magnitude, it is difficult to define a narrow range of values of VoLL for typical situations or countries. Some relevant work was done within the framework of the CASES[1] research project (Markandya, Bigano, & Porchia, 2010), which report a VoLL of 4-40 \$/kWh for developed countries and 1-10 \$/kWh for developing countries.

[1] Available at http://www.feem-project.net/cases/

2.1 Top-down approaches

Many researchers use top-down frameworks to estimate the VoLL, especially when dealing with firms and sectors, as they identify losses in production. They have similarities to the estimation of production functions, in which the relation between input and output of economic processes taken from empirical data is expressed in terms of parameter of a mathematical specification. Here the relation arises from electricity as an input to realize the product of the economy (the value added). Very simple functional forms are usually used to model this input-output relationship. The most popular is the Leontief production function, with a condition of linearity between inputs of production of an economic sector and its output. Exercises implementing this method, defined as the *production function approach*, consider the macroeconomic accounts of value added and the consumption of electricity as the terms of a ratio representing the VoLL:

$$\boldsymbol{VoLL_{ic}} = \frac{\boldsymbol{GVA_{ic}}}{\boldsymbol{EC_{ic}}} \qquad [1]$$

where GVA_{ic} expresses the annual Gross Value Added (in euros) of sector i in country c, and EC_{ic} is the annual electricity consumption in kilowatt-hours (kWh).

This ratio defines to what extent one unit of output is associated to the use of 1 kWh of electricity. In this manner it determines which sectors or regions would be most severely affected by rationing of power, e.g. in cases of network congestion. This can be used to determine production losses resulting from a disruption. To estimate the losses, information on the regular production intensity during the blackout is required. Equation [2] calculates the total outage cost. In particular, building on the proportionality assumption, the total electricity consumption of sector i during the time span t can be used to obtain the outage costs (O):

$$O_{ict} = VoLL_{ic} \cdot EC_{ict} \qquad [2]$$

One critical aspect of such methods is in the assumption of a linear relationship between electricity and value added, and some authors consider the method can underestimate or overestimate the VoLL with respect to the real loss in production.

The use of annual data to quantify the production in terms of value added is a weak point, that can induce both over and underestimation of the VoLL (de Nooij, Koopmans, & Bijvoet, 2007). The approach illustrated by equations [1] and [2] departs from annual data that averages the output-input ratio over the whole year. The same ratio calculated on smaller time span may offer results significantly diverging from the value of actual damage experienced by customers.

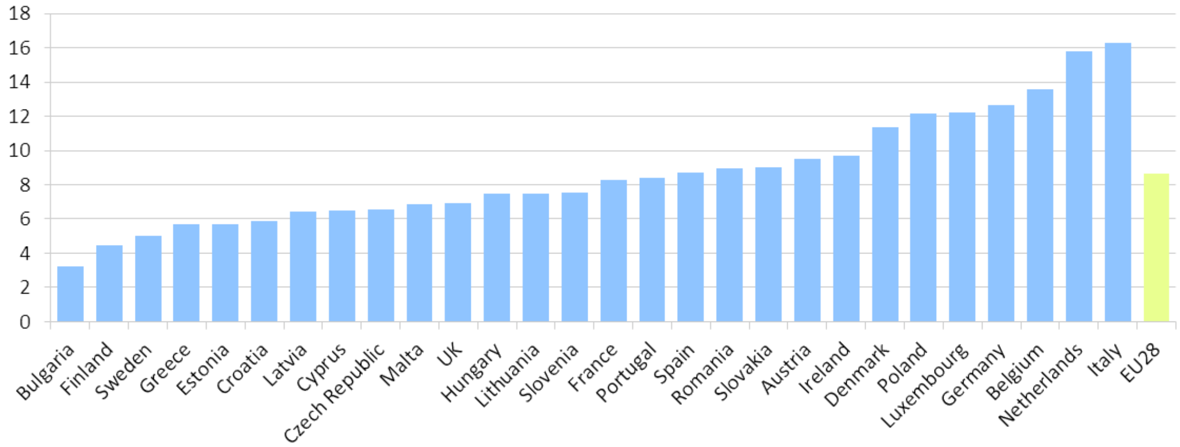
The use of a finer time granularity for the term EC_{ict} has been employed to determine the time dynamic of the VoLL keeping into consideration with more accuracy the peaks and lows of consumption, but this does account for seasonal effects in the production of value (Zachariadis & Poullikkas, 2012). The bias may be relevant when assessing the damage to activities and services that operate with long breaks during the year, as in the case of educational services.

The production function method is also applied to provide the VoLL for residential consumers. An outstanding work (de Nooij, Koopmans, & Bijvoet, 2007) considered as a reference in the field applies the concept of lost leisure time to define, for households, an equivalent to the loss of value added. Researchers usually consider that residential consumer use electricity as a fuel to produce services for their leisure time. The monetization of the loss in the possibility to perform leisure time activities is the equivalent of the value added defined for the case of firms. In the papers examined, the value of wages is used as a proxy for the value of the lost leisure time. This follows an economic theoretical proposal, formulated to determine the optimal allocation of time. Under a condition of optimality, the value of one additional hour of leisure time equals the marginal wage given by one worked hour (Becker, 1965). Such approach has been extensively adopted by many applications of the production function in the framework of VoLL assessments. It can be agreed that there are some advantages in using wages as a proxy, as wage data are generally available. Other approaches are also available to evaluate the value of leisure time. In fact, it is important to note that even under certain (optimal) conditions, the assumption that the value of losing leisure time equals marginal wages (Becker, 1965) may theoretically be correct, but its use for the practice of estimation of VoLL can be questioned. The method could sensibly overestimate the damage, for individual not using electricity for leisure time activities, and vice versa underestimating the damage for those activities that depends only on electricity. Being unemployed or other exogenous constraints may as well determine a substantial distance between the real allocation and the optimal one. Other national studies using the production function approach are available for Germany (Wolf & Wenzel, 2016), Portugal (Castro, Faias, & Esteves, 2016), Spain (Linares & Rey, 2012), and a study for Austria (Reichl, Schmidthaler, & Schneider, 2013). This last is probably at the forefront in this stream of research. The damage of the households in this work is obtained through a survey and not the production function.

In the case of the Netherlands and Germany, regional differences in the VoLL were explored by scaling to a local dimension the assessment to produce maps, where the market based approach based on the production function has been applied to determine county specific values, proposing the idea that power outages may be optimized curtailing zones with lower VoLL to minimize the damage, according to economic criteria (de Nooij, Lieshout, & Koopmans, 2009).

The application of production function with the largest EU coverage (Shivakumar, et al., 2017) provided an exercise of production function for each member state, whose main results are illustrated in Figure 2. It can be seen how the range of values is quite dispersed, from 3.2 €/kWh for Bulgaria to 15.8 €/kWh for the Netherlands. The Agency for the Cooperation of Energy Regulators (ACER) recently published an important study for the estimation of the VoLL for residential and non-residential customers based on the production function approach (Cambridge Economic Policy Associates, 2018). Applications of the production function approach are presented in Table 3.

Figure 2: Country specific VoLL for EU28 in €/kWh obtained via production function approach



Source: own elaboration on results from (Shivakumar, et al., 2017)

2.2 Bottom-up approaches: survey of electricity customers

Surveys are commonly used to assess the VoLL, especially by distribution system operators when acquiring information on the (dis)satisfaction that customers regarding the service of electricity supply. Both quantitative and qualitative data can be collected through structured questionnaires, e.g. the value of *perceived* damage costs during blackouts.

For example, (Targoz & Manson, 2007) conducted 62 face-to-face interviews in eight European countries to explore the relationship between poor quality of electricity supply (including blackouts) and (perceived) damages. One of the main conclusions of the study is that even though poor quality costs in Europe are responsible for reducing industrial performance with an economic impact exceeding €150bn, many in the sector are ignorant of the problem.

2.2.1 Techniques for the analysis of stated preferences

Stated preferences based non-market valuation techniques use questionnaires to elicit respondents' preferences, attitudes and their WTP or WTA for hypothetical scenarios of improvements or deterioration from the current situation. For estimating the VoLL, respondents are asked to choose between the current situation and one of the hypothetical scenarios described in terms of changes to the reliability of the electricity supply and costs to the respondents. This method has its theoretical roots in welfare economics: researchers elicit the choices a consumer would take and model the choice process within a utility maximization framework. Providing the consumer with a choice between uninterrupted electricity supply and monetary compensations for blackouts, can reveal her WTP or WTA, allowing researchers to estimate a proxy for the value of the damage avoided or accepted.

The responses to the elicitation questions are typically outcomes of choice behaviours. They are coded into databases in the form of variables and analysed through econometric methodologies. The Random Utility framework is the main theoretical construct at the basis of stated preferences analyses; it is presented in detail in the next section of this report. Theoretical and applied choice analyses have applied state preference approaches in many fields, from urban studies to transport engineering, health economics, energy economics, but mostly in the field of the evaluation of environmental goods and natural resources. Given the very large core of empirical work in many fields, it is difficult to produce a unitary meaningful sample of references, although (Johnston, et al., 2017) provide a detailed overview on the methodological refinements and the good practices that should guide the application of the stated preference approach.

In comparing the possibility to face inconveniences from blackouts within hypothetical scenarios, consumers are asked, for example, to choose if receiving a compensation for a specific duration/type if blackouts may be preferable to the damage they would suffer otherwise. Alternatively, they may be asked if they would be WTP a certain amount to obtain an increase of the reliability of the system, i.e. to avoid blackouts.

The most popular elicitation formats are based on:

- Contingent Valuation (CV). In its dichotomous format[(2)], the respondent accepts/rejects a hypothetical change to a situation with lower/higher reliability of the power supply (Woo, Shiu, Cheng, Horowitz, & Wang, 2014).
- Discrete choice experiments (DCE). The respondent has more than two mutually alternative scenarios. Each alternative is described through quantitative and qualitative attributes. Choosing the preferred one and repeating the choice exercise in different combinations of the attributes, the respondent offers information to derive the importance she puts on the attributes of the alternatives (Longo, Markandya, & Petrucci, 2008) (Pepermans, 2011) (Ratha, Iggland, & Andersson, 2013) (Boeri & Longo , 2017).
- Other methods, such as conjoint analyses (Baarsma & Hop, 2009). Applications of stated preferences evaluation studies are presented in Table 4.

Some consumers' surveys have also directly asked an evaluation on outage costs/damages, in the form of open ended questions (Billinton, et al., 2001). Open ended questions refer to a general overall assessment of the damage, or a more analytical breakdown, as shown in Table 2.

Furthermore, some studies[3] on the VoLL tried to elicit personal opinions, preferences and attitudes of consumers on VoLL through in-depth interviews and focus groups. In these studies, consumers are asked to

(2) Many formats of Contingent Valuation have been developed years, but the dichotomous choice format remains the most popular (Carson, 2000).

extensively discuss their tolerance and their perspectives on the fact that the reliability of the power supply is not by definition granted, e.g. due to the evolution of the power system towards a low-carbon economy (Kennelly & Quigley, 2016).

Table 2. Example of questionnaire section seeking for an analytical description of the damage cost components via open questions

Costs of the		
Damage to equipment	________________________	euros
Damage to materials	________________________	euros
Wages paid without production	________________________	euros
Other costs	________________________	euros
Lost sales (or production)	________________________	euros
Savings induced by the outage:		
Wages saved	________________________	euros
Energy costs saved	________________________	euros
Other savings	________________________	euros

Source: (Billinton, et al., 2001)

The stated preference approach was chosen for this study. In particular, we used a survey mechanism to have the possibility to assess separately the WTP for improvements in electricity supply reliability, and the WTA for reliability deterioration. The sub-section illustrates the methodology in further detail.

2.3 The valuation strategy

We opted for assessing hypothetical positive and negative changes in the reliability of the power supply, thus assessing the performance of the supply over a prolonged time span. The asymmetry between gain and losses in reliability has not been thoroughly addressed in previous studies, and one critique to the use of stated preferences is represented by the difficulty in the use of the appropriate proxy. WTP is generally found to be lower than WTA, and economic theory suggests that WTP should be used when a good is offered to respondents, while WTA is more appropriate when respondents are asked to give up a good that they already own.

As we are interested in assessing both the values of increasing (WTP) and decreasing (WTA) the reliability of the electricity supply, two hypothetical scenarios were explored:

- The value gained from a better power system. In this case, the VoLL refers to avoided damage, represented by the WTP for improvements. Thus, the VoLL is more a value of "gained" load from the load that would be otherwise lost.
- The value lost from decreased performance. In this case, for a consumer experiencing more power outages than usual, researchers need to estimate the minimum amount that would compensate the consumer for the loss of reliability of the power supply.

[3] See for example the study reported by a British Distribution System Operator (Electricity North West) available at https://www.enwl.co.uk/globalassets/innovation/enwl010-voll/voll-ecp-and-survey/voll-depth-interviews-report.pdf

Table 3: Applications of the production function approach

Authors	Evaluation Method	Description	Residential	Agriculture	Industry	Construction	Commerce, service and transportation	Public administration	Whole economy
(Targoz & Manson, 2007)	Direct assessment	Survey on costs of real outages							
(Praktiknjo, Hahnel, & Erdmann, 2011)	Production function approach (wages)	Wages, electricity consumption and time of use are introduced in a Monte Carlo analysis	15.70	2.34	2.49		16.35	5.53	6.06
(Zachariadis & Poullikkas, 2012)	Production function approach (2009)	Cyprus		2.30	1.91(*)	118.06	6.12	11.63	6.50
(Reichl, Schmidthaler, & Schneider, 2013)		Austria							
(Wolf & Wenzel, 2016)	Production function approach	Germany, exploring regional heterogeneity	6.96-15.11(**)	1.98	0.48-12.49(**)	118.15	10.16		
(de Nooij, Koopmans, & Bijvoet, 2007)	Production function approach (2001)	Netherlands		3.90	3.90	33.05	7.94 (***)	33.50	8.56
(Castro, Faias, & Esteves, 2016)	Production function approach (2010)	Portugal	7.43	3.38	1.28	15.52	6.67		5.12

(*) In the table is reported the value for manufacturing activities, but the study offers an accurate breakdown including other activities

Table 4: Stated preferences evaluation studies

Authors	Method	Attributes	Value of reliability	Unit of measure	Region
(Goett, Hudson, & Train, 2000)	DCE Phone interviews	Sign up bonuses, renewables, billing options, bundling with other services, reduction in voltage fluctuations, charitable contributions	Customers are willing to pay, on average, 1.21 cents per kWh to reduce outages from 4 30-minutes outages to 2 such outages per year	$\$_{2000}$	
(Cai, Deilami, & Train, 1998)	CV DB	Renewables, level of reliability, quality of customers service, assistance to energy savings service	On average, customers would require a 23.88 % price reduction in order to accept more outages.	Percentage change on electricity bill	California
(Carlsson, Martinsson, & Akay, 2011)	CV OE		Mean WTP 6.3		Sweden
(Carlsson & Martinsson, 2008)	DCE RPL	Duration, weekend, winter outages	The WTPs for reducing unplanned power outages of 4 and 8 h were 21.54 and 60.60 SEK respectively	SEK_{2003}	Sweden
(Bertazzi, Fumagalli, & Lo Schiavo, 2005)	CV OE	No multiattribute analysis	For one hour outage, normalised to the unserved energy amount, 10.39 Euro/kWh	$€_{2005}$	Italy
(Hensher, Shore, & Train, 2014)	DCE	Duration of power outages, frequency in the year, prior notification, customer service	For one hour outage, WTA of 4.6 % price reduction	$\$_{2014}$	
Nordic Study 1992-93	WTP	Winter weekday, during annual peak demand	2.722 $/kWh	$\$_{2000}$	Denmark
Nordic study 1992-93	WTP	Winter weekday, during annual peak demand	3.157 $/kWh	$\$_{2000}$	Finland
Nordic study 1992-93	WTP	Winter weekday, during annual peak demand	1.524 $/kWh	$\$_{2000}$	Iceland

DCE: discrete choice experiment CV: Contingent Valuation RPL: Random Parameter Logit DB: Double Bounded WTP: willingness-to-pay WTA: willingness-to-accept

3 Discrete Choice Experiments

A discrete choice experiment (DCE) is a survey-based technique used to investigate the trade-offs that people are prepared to make between different goods or policies. The technique can be used to find the monetary value that people place on goods and services or the value of a policy change. DCE is a stated-preference technique which relies on individuals saying what they would do under alternative hypothetical circumstances, rather than observing actual behaviours in marketplaces. Contingent Valuation (CV) is a popular method for placing a value on a good, and is another example of a stated-preference technique which can be interpreted as a special case of DCE.

In a typical DCE survey, respondents are shown alternative variants of a good described by a set of attributes, and are asked to choose the most preferred one. The alternatives differ from one another in the levels taken by two or more of the attributes. Statistical analyses of the responses can be used to obtain the marginal value of these attributes and the WTP for any alternative of interest.

In this project, the DCE process involves presenting customers with alternative scenarios of power cuts arranged according to the principles of experimental design, and asking them to choose their favourite scenario from the available set. To establish trade-offs between the power cut characteristics and money, one of these characteristics must be the cost of the bundle. When customers choose one bundle (package of electricity services) over others, they implicitly reveal their trade-off between money and the single services included in each bundle in their choice set. Such a trade-off is the marginal value of that characteristic of the complex good.

DCEs have been widely used for valuing the value of lost load. See for example (Praktiknjo A. J., 2014; Praktiknjo, Hahnel, & Erdmann, 2011; von Selasinsky, Schubert, Meyer, & Most, 2017) and also (Carlsson, Martinsson, & Akay, 2011; Reichl, Schmidthaler, & Schneider, 2013) and (Pepermans, 2011) (Longo, Markandya, & Petrucci, 2008). Among recent applications the one developed for OFGEM and DECC of Great Britain (London Economics, 2013)

3.1 Model and econometric analyses of the responses

3.1.1 The Random Utility Model

In a DCE, respondents are shown a set of alternative representations of a good and are asked to pick their most preferred. The responses can be used to estimate the marginal rates of substitution between attributes. If one of the attributes is cost, it is possible to calculate the marginal price for an additional unit of each attribute. If the "do nothing" or status quo option is included in the choice set, the experiments can be used to compute the full value (WTP) of each alternative. This approach has the advantage of simulating real market situations, where consumers face two or more goods characterized by similar attributes, but different levels of these attributes, and are asked to choose whether to buy one (or none) of the goods. Another advantage is that the choice tasks do not require as much effort by the respondent compared to rating or ranking alternatives. The Random Utility Theory is the methodological framework adopted for the study. Annex C describes in detail the econometric models employed for the choice analyses.

3.1.2 Experimental design

Once the attributes and their levels of a DCE are selected and grouped into subsets, researchers use the theory of experimental design to combine attribute levels into bundles of electricity services to produce the DCE choice cards to optimize the amount of information that can be collected from a sample of a given size. Researchers typically start with building a full factorial design, which comprises all the possible combination of attribute levels. However, as such a design tends to produce a very large number of possible combinations that cannot be evaluated with a limited sample of respondents; researchers use a fractional factorial design. Recent research in experimental design revolves around asymptotic measures of efficiency, such as the D-error. This is the determinant of the asymptotic estimator of the variance covariance matrix of a given model specification. This means that before deriving a design, first a specification must be assumed, and then some values for the unknown coefficients need also to be assumed. In this study a balanced D-error minimizing design was used in all cases. The model specification was the conventional MNL, which has been shown to produce well-performing designs with other specifications as well. The assumptions on the values of unknown coefficients were derived from the results of the pilot study. Using these assumptions, D-efficient designs were derived. Attributes levels were as follows: cost had the status quo (no increase in the electricity bill under the current situation) and 4 levels (change in the annual electricity bill of 1 euro, 5 euros, 10 euros, 20 euros), and all the other attributes had the status quo (level 0) plus two levels. These attributes entail changes in the number and duration of planned and unplanned power outages. The design used included choice tasks of three alternatives each, one of which was the current situation and the other two involved blackout scenarios. Each respondent was shown 5 choice cards where we showed an improvement to the service – to estimate WTP – and 5 choice cards with a deterioration to the service – to estimate WTA. We randomly allocated respondents to two versions of the questionnaire: one first version showed the WTP questions before the WTA questions and the other showed first the WTA questions followed by the WTP questions. Tables 5 and 6 shows the attributes and levels 1 for the DCE questions and Table 7 reports an example of DCE WTA choice card. We assumed the current situation to entail 4 planned power outages, lasting 10 hours, 10 unplanned power outages, lasting 10 hours over the next 10 years for all countries. We chose this current situation considering the past power outages in EE, NL and PT did not show any particular pattern in the number and duration of power outages.

Table 5: Attributes and levels of the DCE questions: WTA

Attribute	Current situation	Level 1	Level 2	Level 3	Level 4	Level 5
Number of **planned** power outages in the next 5 years	4	5	6			
Duration of **planned** power outages in the next 5 years	10 hours	15 hours	18 hours			
Number of **unplanned** power outages in the next 5 years	10	15	18			
Duration of **unplanned** power outages in the next 5 years	10 hours	15 hours	18 hours			
Electricity bill	No change	€1 discount on electricity bill per year	€3 discount on electricity bill per year	€5 discount on electricity bill per year	€10 discount on electricity bill per year	€20 discount on electricity bill per year

Source: own elaboration

Table 6. Attributes and levels of the DCE questions: WTP

Attribute	Current situation	Level 1	Level 2	Level 3	Level 4	Level 5
Number of **planned** power outages in the next 5 years	4	3	2			
Duration of **planned** power outages in the next 5 years	10 hours	5 hours	2 hours			
Number of **unplanned** power outages in the next 5 years	10	5	2			
Duration of **unplanned** power outages in the next 5 years	10 hours	5	2			
Electricity bill	No change	€1 increase on electricity bill per year	€3 increase on electricity bill per year	€5 increase on electricity bill per year	€10 increase on electricity bill per year	€20 increase on electricity bill per year

Source: own elaboration

Table 7. Example of WTA choice card

Number of **planned** power outages in the next 5 years	6	4	4
Duration of **planned** power outages in the next 5 years	18 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	10	10	10
Duration of **unplanned** power outages in the next 5 years	15 hours	18 hours	10 hours
Electricity bill	€1 discount on electricity bill per year	€3 discount on electricity bill per year	No change
Which option would you choose?			

Source: own elaboration

3.1.3 Estimation strategy

The estimation of the DCE data started with basic MNL models that assume that all respondents have the same preferences. We then accommodate for heterogeneous preferences using first MNL models augmented with socio-economic characteristics, to explore how variables such as location where respondents live, respondents' age, gender, employment status, household size, electricity bill, income, and experience with planned and unplanned power cuts affect WTP. Therefore, we built the variables shown in Table 8 and interact them with the Current Situation (CS). Then we further explore heterogeneity by running RPL models and by augmenting these models with interactions between number and duration of unplanned power outages.

When estimating the models with socio-economic variables, we would expect that households with a higher income might be willing to pay more than households with lower income. For many other variables, we do not have clear a priori expectations. For example, on the one hand, it is possible that households with a low electricity bill might be willing to pay more because they might think that the price they are currently paying for electricity is low. On the other hand, it is also possible that households with a low electricity bill might be willing to pay less than customers with a high electricity bill because they might consider that, as they are consuming less electricity than other customers, it should be those consuming more electricity that should pay more for the service.

The coefficient estimate for the CS will capture the effect of choosing the current situation, and all the other variation not captured by the attribute levels and the error term. A positive and statistically significant coefficient for CS, will indicate that respondents are, on average, more willing to pick the current situation than a hypothetical policy.

When estimating the models, to assess which models fit the data better, conventional information criteria, such as the Akaike Information Criterion (AIC), or the Bayes Information Criterion (BIC) can be used. These criteria measure the relative goodness-of-fit of statistical models for a given set of data. The AIC is calculated from the Log likelihood function (LL) of the model and the number of estimated coefficients. With k estimated coefficients in the model, the AIC is given by the following:

$$AIC = 2 * k - 2 * LL \quad [22]$$

Given a set of candidate models for the data, the preferred model is the one with the minimum AIC value. While the AIC rewards goodness-of-fit, it also includes a "penalty" that is an increasing function of the number of estimated parameters. The penalty discourages overfitting (increasing the number of parameters in the model almost always improves the goodness of the fit).

All these models had utility specified as changes from the current state of service provision, the CS. This implies that only changes in utility are estimated from a common reference point and coefficients are easily interpretable as jumps from the baseline condition to the level of factor service improvement. For each attribute a coefficient for the two improvement levels were estimated. All models estimated by simulated maximum likelihood were estimated with at least 500 Halton draws. All the assumptions of random coefficients models were of normal distributions, while the cost coefficient was assumed to be constant.

We estimate two sets of DCE models for each country to estimate both WTP for an improvement of the quality of the electricity provision and WTA for a deterioration of the provision of electricity.

Table 8. Socio-economic and attitudinal variables and definitions

Variable	Definition
age	Age of respondents
female	Dummy variable equal to 1 if the respondent is female, 0 otherwise
hsize	Number of persons in the household
lincome	Logarithm of income
incmiss	Dummy variable equal to 1 if no information is reported for income, and 0 otherwise
bigcity	Dummy variable equal to 1 if the respondent lives in a big city, and 0 otherwise
village	Dummy variable equal to 1 if the respondent lives in a country village, and 0 otherwise
countryside	Dummy variable equal to 1 if the respondent lives in a farm or a home in the countryside, and 0 otherwise
town	Dummy variable equal to 1 if the respondent lives in a town or a small city, and 0 otherwise
qa2_1 available	Thinking about energy security for your country of residence in the next five years you, how important it is for you to have a secure supply of oil, gas, coal and uranium (1=extremely unimportant; 5=extremely important)
qa2_5 affordable	Thinking about energy security for your country of residence in the next five years you, how important it is for you to have affordably priced energy services (1=extremely unimportant; 5=extremely important)
qa2_13 clean_water	Thinking about energy security for your country of residence in the next five years you, how important it is for you to provide available and clean water (1=extremely unimportant; 5=extremely important)
qa2_15 adaptation	Thinking about energy security for your country of residence in the next five years you, how important it is for you to minimize the impact of climate change (i.e. adaptation) (1=extremely unimportant; 5=extremely important)
qa2_16 GHGmitigation	Thinking about energy security for your country of residence in the next five years you, how important it is for you to reduce the greenhouse gas emissions (i.e. mitigation) (1=extremely unimportant; 5=extremely important)
unpldurm3	Dummy variable equal to 1 if the longest unplanned outage that the respondent experienced in last year lasted more than 3 hours, and 0 otherwise
q56_56 Esaving	I want to reduce my energy consumption (1=completely disagree; 5=completely agree)
q56_57 regret	If I don't support the implementation of the EU Energy Security Strategy, and then I will be restricted with the use of energy, I will later wish that I had (1=completely disagree; 5=completely agree)
q56_58	If I don't support the implementation of the EU Energy Security Strategy, and then my family will be restricted with the use of energy, I will later feel bad for my family (1=completely disagree; 5=completely agree)
Hed	Importance of hedonic value (1=entirely not like me; 7=entirely like me)
Ego	Importance of egoistic value (1=entirely not like me; 7=entirely like me)
Alt	Importance of altruistic value (1=entirely not like me; 7=entirely like me)
Bio	Importance of biospheric value (1=entirely not like me; 7=entirely like me)

Source: own elaboration

3.2 Survey implementation and data collection

Age and gender criteria have driven the construction of the sample. A comparison between the sample of participants to the survey and the target population is illustrated in Table 9. Younger respondents were excluded from our design to focus on preferences of those who are usually the ones purchasing security as embedded within their choices as consumers (e.g. energy contract), or voters. Younger citizens are less likely to have a say or responsibility with regard to energy, and less familiarity with purchase decisions under income constraints[4]. Differences between the target and the obtained number of interviews are reported in Table 9, where differences remained within the 5 % deviation threshold. To our knowledge, the only existing multicountry survey developed in the EU evaluating benefits of security of electricity supply has been carried out on the framework of the SESAME EU research project. For a pan-European survey providing country specific evaluations of VoLL, the SESAME project counted on about 250 interviews per country, for a total of 27 countries. Our study covered three countries, with a target sample size of 1000 interviews per country.

Table 9. Count of data collected in the fieldwork compared to the sampling design

			target	obtained	diff
Estonia	male	25-34	105	76	**-2.58%**
		35-44	105	104	**-0.09%**
		45-54	95	96	**0.09%**
		55-64	84	86	**0.18%**
		65+	84	77	**-0.62%**
	female	25-34	105	105	**0.00%**
		35-44	95	96	**0.09%**
		45-54	95	95	**0.00%**
		55-64	175	183	**0.71%**
		65+	179	125	**-4.81%**
the Netherlands	male	25-34	95	91	**-0.37%**
		35-44	105	101	**-0.37%**
		45-54	116	115	**-0.09%**
		55-64	95	91	**-0.37%**
		65+	116	112	**-0.37%**
	female	25-34	95	91	**-0.37%**
		35-44	105	101	**-0.37%**
		45-54	116	112	**-0.37%**
		55-64	95	91	**-0.37%**
		65+	137	133	**-0.37%**
Portugal	male	25-34	95	96	**0.05%**
		35-44	105	106	**0.05%**
		45-54	105	106	**0.05%**
		55-64	84	85	**0.05%**
		65+	116	118	**0.09%**
	female	25-34	95	96	**0.05%**
		35-44	105	108	**0.14%**
		45-54	105	105	**0.00%**
		55-64	95	97	**0.09%**
		65+	158	142	**-0.75%**

Source: SSI

We opted for online web questionnaires as this interview mode guarantees a good balance between survey costs, quality and speed of data collection. Furthermore, the DCE format is unsuitable for alternative interview techniques, such as telephone interviews, as choice cards are difficult to be used without visual media.

The data collection was contracted to the survey company SSI S.A. (report in Annex B). Three separated series of 10 subversions were scripted for the Estonian, Dutch and Portuguese versions of the questionnaire.

The questionnaires (see Annex A) contain both the DCE for assessing WTP and for WTA. One subsample introduces first the DCE WTP and the other puts first the WTA. These two versions were further split into five subversions, as the questionnaire also contains a Contingent Valuation exercise entailing five different treatments in terms of information for respondents

SSI S.A. gathered an initial pre-test sample to check the functioning of the performance data collection (10 % of the final sample size). Both the data for the DCE and for the Contingent Valuation exercise were scrutinized suggested minimal changes. SSI S.A. also supported the quality checks (duration of the interview, missing data etc.). In total, SSI S.A. provided **1043 completed interviews for Estonia, 1038 for the Netherlands and 1059 for Portugal** (Figure 4).

(4) This last condition is suggested to improve the evaluation of willingness-to-pay to support an hypothetical strategy for energy security of the EU, the objective of the section 3 of the study.

The median length of the interview was 16:31 minutes for the Netherlands, 19:26 for Portugal and 24:00 minutes for Estonia, and the dfferences were likely to be determined by the language particularities and possibly in varying internet speeds.

Figure 3: Numbers of data points collected per interview version

hlang (Single)	hRandom (Single)	hVersions (Single)	Limit	Count
Estonia	WTA - First	Ver-A	1	132
Estonia	WTP - First	Ver-A	1	77
Estonia	WTA - First	Ver-B	1	104
Estonia	WTP - First	Ver-B	1	104
Estonia	WTA - First	Ver-C	1	104
Estonia	WTP - First	Ver-C	1	104
Estonia	WTA - First	Ver-D	1	104
Estonia	WTP - First	Ver-D	1	105
Estonia	WTA - First	Ver-E	1	104
Estonia	WTP - First	Ver-E	1	105
Netherlands	WTA - First	Ver-A	1	120
Netherlands	WTP - First	Ver-A	1	87
Netherlands	WTA - First	Ver-B	1	104
Netherlands	WTP - First	Ver-B	1	104
Netherlands	WTA - First	Ver-C	1	104
Netherlands	WTP - First	Ver-C	1	104
Netherlands	WTA - First	Ver-D	1	104
Netherlands	WTP - First	Ver-D	1	104
Netherlands	WTA - First	Ver-E	1	103
Netherlands	WTP - First	Ver-E	1	104
Portugal	WTA - First	Ver-A	1	109
Portugal	WTP - First	Ver-A	1	102
Portugal	WTA - First	Ver-B	1	106
Portugal	WTP - First	Ver-B	1	105
Portugal	WTA - First	Ver-C	1	106
Portugal	WTP - First	Ver-C	1	106
Portugal	WTA - First	Ver-D	1	106
Portugal	WTP - First	Ver-D	1	106
Portugal	WTA - First	Ver-E	1	107
Portugal	WTP - First	Ver-E	1	106

Source: SSI S.A.

4 Results

In this section we present the results from both the WTP and the WTA DCE questions, and the estimations for the VoLL. We begin by presenting the results of multinomial logit models (MNL), that is, models that only used the attribute levels as explanatory variables to explain people's choices for the different hypothetical scenarios of power outages. The models are estimated with two Alternative Specific Constants (ASCs), one for the first hypothetical alternative and one for the current scenario. These constant terms identify if there is a statistically significant change in utility associated with a specific scenario.

The results from the WTP DCE questions reported in Table 10 show that respondents prefer the (hypothetical) scenarios with a reduction in the number of planned outages, when these outages are halved to 2, compared from the current situation where there are 4 outages. This result is consistent across the three countries.

Table 10. Estimation of MNL models, WTP

	Estonia		**Netherlands**		**Portugal**	
	Mean	Rob. St. Err.	Mean	Rob. St. Err.	Mean	Rob. St. Err.
ASC1 (Alternative 1)	0.057	0.043	0.135***	0.041	-0.008	0.042
ASC3 (Status Quo)	0.729***	0.071	0.901***	0.071	0.811***	0.069
Number of **planned** power outages (baseline = 4):						
3 power outages	0.046	0.053	0.086	0.052	0.056	0.052
2 power outages	0.199***	0.055	0.200***	0.053	0.194***	0.053
Duration of **planned** power outages (baseline = 10 hours):						
5 hours	0.273***	0.055	0.255** *	0.055	0.245***	0.055
2 hours	0.465***	0.051	0.680***	0.050	0.538***	0.050
Number of **unplanned** power outages (baseline = 10):						
5 power outages	0.333***	0.056	0.401***	0.056	0.198***	0.055
2 power outages	0.498***	0.058	0.451***	0.057	0.230***	0.057
Duration of **unplanned** power outages (baseline = 10):						
5 hours	0.389***	0.061	0.411***	0.060	0.453***	0.059
2 hours	0.586***	0.057	0.624***	0.056	0.649***	0.056
Increase in electricity bill	-0.106***	0.005	-0.071***	0.004	-0.080***	0.004
Number of observations		5200		5190		5290
Number of parameters		11		11		11
Log Likelihood		-5183.282		-5313.959		-5379.96
AIC		10388.563		10649.918		10781.921

Source: own elaboration

The most important characteristics for the respondents are the duration and the number of unplanned power outages (Table 10), while they respondents shy away from more expensive scenarios.

Regarding the MNL models for the WTA questions, we find that respondents dislike scenarios with increased number of planned and unplanned outages and scenarios with longer planned outages in all our countries (Table 11). Only in NL, the coefficient estimate for an increase of one planned power outage is not statistically significant.

Table 11. Estimation of MNL models, WTA

	Estonia			Netherlands			Portugal		
	Mean		Rob. St. Err.	Mean		Rob. St. Err.	Mean		Rob. St. Err.
ASC1 (Alternative 1)	-0.273	***	0.049	-0.232	***	0.056	-0.178	***	0.046
ASC3 (Status Quo)	0.816	***	0.076	1.160	***	0.085	0.719	***	0.073
Number of **planned** power outages (baseline = 4):									
5 power outages	-0.124	**	0.058	-0.094		0.066	-0.093	*	0.055
6 power outages	-0.347	***	0.060	-0.191	***	0.067	-0.344	***	0.057
Duration of **planned** power outages (baseline = 10 hours):									
15 hours	-0.188	***	0.061	-0.217	***	0.069	-0.245	***	0.058
18 hours	-0.280	***	0.058	-0.258	***	0.065	-0.334	***	0.055
Number of **unplanned** power outages (baseline = 10):									
15 power outages	-0.225	***	0.062	-0.380	***	0.068	-0.286	***	0.059
18 power outages	-0.291	***	0.062	-0.395	***	0.069	-0.341	***	0.059
Duration of **unplanned** power outages (baseline = 10):									
15 hours	-0.241	***	0.061	-0.179	***	0.068	-0.108	*	0.058
18 hours	-0.363	***	0.063	-0.249	***	0.069	-0.278	***	0.061
Decrease in electricity bill	0.068	***	0.004	0.053	***	0.004	0.074	***	0.004
Number of observations			5200			5190			5290
Number of parameters			11			11			11
Log Likelihood			-4793.087			-4230.401			-5095.761
AIC			9608.173			8482.801			10213.522

Source: own elaboration

The results from the DCE analysis are used to examine respondents' WTP and WTA for a marginal change in each of the attributes and for selected hypothetical scenarios of VoLL, presented in Table 12.

For a single reduction in the number of planned power outages, respondents are WTP €0.44 in EE, €1.21 in NL and €0.71 in PT. Correspondingly, for an increase by one in the number of planned power outages (i.e. deterioration of service) respondents are WTA €1.83 in EE, €1.78 in NL and €1.27 in PT.

For a reduction by 5 of unplanned power outages, the WTP is €2.49 in PT, €3.14 in EE and €5.66 in NL, while the WTA an increase by 5 the number of unplanned power outages is €2.77 in EE, €4.11 in NL and €3.33 in PT.

A change by 5 hours in the number of power outages is valued more when the outage is unplanned than when it is planned, except in PT where an increase in 5 hours of unplanned outages have a low value of only €1.47.

Considering a "best case scenario" for the WTP data, described by the scenario with the least number of power outages and the shortest duration, we find the WTP to be €27.57 in NL, €20.24 in PT and €16.49 in EE.

For the "worst case scenario" in the WTA choice cards (Table 13), described by the scenario with the largest number and longest duration of power outages, we find WTA of €20.70 in NL, €17.65 in PT and €18.87 in EE. Our results are consistent with the literature that tends to find that WTA is generally larger than WTP.

Table 12. WTP for selected scenarios, MNL models

WTP (€/year):	**Estonia**	**Netherlands**	**Portugal**
The "best" scenario (the least number of power outages and the shortest duration):	16.49	27.57	20.24
The "best" scenario for only the **planned** outages (the least number of outages and shortest duration):	6.26	12.41	9.20
The "best" scenario for only the **unplanned** outages (the least number of outages and shortest duration):	10.23	15.16	11.04
1 **planned** power outage **reduction** (from 4 to 3):	0.44	1.21	0.71
5 hour **decrease** of **planned** outage (from 10h to 5h):	2.58	3.60	3.08
5 **unplanned** power outage **reduction** (from 10 to 5):	3.14	5.66	2.49
5 hour **decrease** of **unplanned** outage (from 10h to 5h):	3.67	5.80	5.69

Source: own elaboration

Table 13. WTA for selected scenarios, MNL models

WTA (€/year):	**Estonia**	**Netherlands**	**Portugal**
The "worst" scenario (the most number of power outages and the longest duration):	18.87	20.70	17.65
The "worst" scenario for only the **planned** outages (the most number of outages and longest duration):	9.23	8.50	9.22
The "worst" scenario for only the **unplanned** outages (the most number of outages and longest duration):	9.63	12.20	8.42
1 **planned** power outage **increase** (from 4 to 5):	1.83	1.78	1.27
5 hour **increase in planned** outages (from 10h to 15h):	2.77	4.11	3.33
5 **unplanned** power outage **increase** (from 10 to 15):	3.31	7.20	3.89
5 hour **increase** of **unplanned** outage (from 10h to 15h):	3.55	3.39	1.47

Source: own elaboration

Next, we explore the effect of observed heterogeneity by running MNL models with interaction terms between the alternative specific constant for the status quo (ASC 3 (Status Quo)) and socio-economic and attitudinal variables. Results for these models are reported in Tables 14 and 15. We add four sets of variables to examine the effects of: (i) socio-economic variables, (ii) the importance of Energy Security on WTP, (iii) experience with unplanned power outages and regret if the EU Energy Strategy is not implemented, and (iv) personal values.

The models with interaction terms for the WTP DCE questions show that respondents have different preferences across the three countries. In EE, older respondents prefer the alternative (hypothetical) scenarios, in NL they prefer the current situation, and in PT age does not affect the relevant preferences.

Female respondents are more likely to choose the hypothetical programmes in EE and PT, but not in NL. In all countries, richer households are more willing to choose the hypothetical programmes, and hence to support the investments in improving the short term supply of electricity.

We also find that respondents in all countries who think that it's important to minimize the impact of climate change (i.e. adaptation) when considering energy security for the country they reside in, are more likely to support the implementation of the hypothetical programmes.

In EE and the NL we also find that respondents who have experienced unplanned blackouts longer than three hours are more likely to support programmes that improve the reliability of the electricity supply. For all countries, respondents who would regret not supporting the implementation of the EU Energy Security Strategy are much more likely to choose the hypothetical programmes with fewer blackouts.

Personal values have different effects in the three countries on the likelihood of choosing the status quo or the alternative hypothetical scenarios of improvement in power outages. In EE and PT, people with more egoistic values are more likely to choose the status quo option. In NL, respondents with more hedonic values tend to choose more often the current situation, while people with more biospheric values are more likely to choose the scenarios of improved reliability of electricity supply.

The WTA MNL models with interaction terms confirm many of the findings of the WTP MNL models. Older respondents prefer scenarios that do not offer a deterioration of the electricity supply service in all the three countries.

While female respondents in EE are willing to accept a scenario that offers discounts on the electricity bill and an increase in power outages, in PT they prefer the current situation. In EE and PT richer respondents are less willing to accept a reduction in the electricity bill associated with a deterioration of the electricity supply.

In all countries, respondents are more likely to choose the status quo the more they consider important to provide available and clean water as a dimension of energy security.

Respondents who want to reduce their energy consumption are more likely to favour the current situation in NL, while in PT and EE they are more likely to choose hypothetical scenarios that compensate them for accepting more frequent and longer power outages. In all countries, respondents with strong altruistic values are more likely to choose the current situation, while respondents with egoistic values prefer a reduction in the electricity bill and a deterioration in the electricity supply.

Table 14. MNL with interaction terms, WTP data

	Estonia			Netherland			Portugal		
	Mean		Rob. St. Err.	Mean		Rob. St. Err.	Mean		Rob. St. Err
ASC1 (Alternative 1)	0.060		0.043	-0.132	***	0.041	-0.006		0.042
ASC3 (Status Quo)	3.500	***	0.524	4.560	***	0.514	2.310	***	0.505
ASC3 x age	-0.005	**	0.002	0.012	***	0.002	0.004		0.002
ASC3 x big city	-0.184	*	0.099	-0.145		0.095	-0.061		0.078
ASC3 x countryside	0.439	***	0.119	0.003		0.205	-0.272		0.217
ASC3 x female	-0.298	***	0.066	0.153	**	0.063	-0.165	***	0.061
ASC3 x hsize	0.035		0.026	0.079	***	0.029	-0.046	*	0.027
ASC3 x incmiss	-2.510	***	0.455	-3.120	***	0.527	-1.850	***	0.440
ASC3 x lincome	-0.280	***	0.040	-0.300	***	0.042	-0.196	***	0.040
ASC3 x town	-0.052		0.098	-0.156	*	0.088	-0.109		0.077
ASC3 x village	-0.199	*	0.107	-0.090		0.098	0.131		0.120
ASC3 x qa2_1	0.087	***	0.032	-0.040		0.030	-0.003		0.030
ASC3 x qa2_13	0.004		0.073	-0.337	***	0.057	0.114		0.083
ASC3 x qa2_15	0.085		0.056	0.154	**	0.067	0.136	**	0.066
ASC3 x qa2_16	-0.190	***	0.055	-0.130	*	0.069	-0.147	*	0.078
ASC3 x qa2_5	0.087		0.057	0.100	**	0.047	0.010		0.054
ASC3 x unpldurm3	-0.216	**	0.100	-0.310	**	0.157	-0.187		0.130
ASC3 x q56_56	0.022		0.019	-0.005		0.020	0.048	**	0.024
ASC3 x q56_57	-0.135	***	0.022	-0.037		0.028	-0.077	**	0.038
ASC3 x q56_58	-0.094	***	0.021	-0.178	***	0.028	-0.125	***	0.039
ASC3 x alt	0.016		0.043	0.035		0.042	0.031		0.046
ASC3 x bio	0.052		0.036	-0.140	***	0.034	0.033		0.037
ASC3 x ego	0.062	**	0.031	0.023		0.028	0.046	*	0.027
ASC3 x hed	0.044		0.035	0.214	***	0.036	0.004		0.035
Number of **planned** power outages (baseline = 4):									
3 power outages	0.057		0.054	0.094	*	0.053	0.063		0.052
2 power outages	0.205	***	0.055	0.210	***	0.054	0.197	***	0.054
Duration of **planned** power outages (baseline = 10 hours):									
5 hours	0.290	***	0.055	0.261	***	0.055	0.254	***	0.055
2 hours	0.483	***	0.051	0.688	***	0.050	0.546	***	0.050
Number of **unplanned** power outages (baseline = 10):									
5 power outages	0.345	***	0.057	0.410	***	0.057	0.205	***	0.056
2 power outages	0.504	***	0.059	0.459	***	0.058	0.232	***	0.058
Duration of **unplanned** power outages (baseline = 10):									
5 hours	0.391	***	0.062	0.422	***	0.061	0.462	***	0.060
2 hours	0.597	***	0.057	0.644	***	0.056	0.664	***	0.057
Increase in electricity bill	-0.108	***	0.005	-0.073	***	0.004	-0.081	***	0.004
Number of observations	5200			5190			5290		
Number of parameters	33			33			33		
Log Likelihood	-5011.469			-5148.761			-5267.5		
AIC	10088.939			10363.521			10601.001		
BIC	10305.3			10579.819			10817.928		

Source: own elaboration

Table 15. MNL with interaction terms, WTA data

	Estonia			Netherland			Portugal		
	Mean		Rob. St. Err.	Mean		Rob. St. Err.	Mean		Rob. St. Err.
ASC1 (Alternative 1)	-0.273	***	0.049	-0.237	***	0.057	-0.180	***	0.047
ASC3 (Status Quo)	-2.530	***	0.516	0.021		0.516	-1.870	***	0.507
ASC3 x age	0.004	*	0.002	0.021	***	0.003	0.005	**	0.002
ASC3 x big city	-0.102		0.099	-0.257	**	0.100	-0.062		0.079
ASC3 x countryside	-0.123		0.121	0.015		0.216	-0.705	***	0.233
ASC3 x female	-0.129	**	0.064	0.071		0.067	0.332	***	0.060
ASC3 x hsize	-0.008		0.026	-0.034		0.028	-0.068	**	0.027
ASC3 x incmiss	2.080	***	0.461	0.042		0.620	1.570	***	0.448
ASC3 x lincome	0.231	***	0.038	-0.042		0.044	0.138	***	0.040
ASC3 x town	-0.077		0.098	-0.039		0.095	-0.370	***	0.077
ASC3 x village	-0.269	**	0.107	-0.113		0.104	-0.090		0.122
ASC3 x qa2_1	0.012		0.031	0.020		0.033	0.009		0.029
ASC3 x qa2_13	0.351	***	0.071	0.224	***	0.058	0.261	***	0.082
ASC3 x qa2_15	0.021		0.056	-0.051		0.068	-0.169	**	0.068
ASC3 x qa2_16	-0.199	***	0.055	-0.081		0.070	0.040		0.076
ASC3 x qa2_5	0.113	**	0.055	-0.060		0.048	0.100	*	0.053
ASC3 x unpldurm3	0.079		0.100	0.622	***	0.183	-0.291	**	0.130
ASC3 x q56_56	-0.076	***	0.019	0.082	***	0.022	-0.085	***	0.025
ASC3 x q56_57	0.060	***	0.021	-0.133	***	0.031	0.024		0.038
ASC3 x q56_58	-0.046	**	0.021	0.055	*	0.031	-0.029		0.038
ASC3 x alt	0.086	**	0.042	0.229	***	0.044	0.174	***	0.047
ASC3 x bio	0.045		0.035	-0.036		0.037	-0.132	***	0.038
ASC3 x ego	-0.087	***	0.031	-0.182	***	0.032	-0.048	*	0.027
ASC3 x hed	-0.073	**	0.034	-0.017		0.036	0.085	**	0.036
Number of **planned** power outages (baseline = 4):									
5 power outages	-0.119	**	0.058	-0.099		0.067	-0.098	*	0.055
6 power outages	-0.345	***	0.061	-0.205	***	0.068	-0.352	***	0.057
Duration of **planned** power outages (baseline = 10 hours):									
15 hours	-0.194	***	0.062	-0.221	***	0.070	-0.250	***	0.058
18 hours	-0.284	***	0.058	-0.264	***	0.065	-0.338	***	0.055
Number of **unplanned** power outages (baseline = 10):									
15 power outages	-0.234	***	0.062	-0.397	***	0.069	-0.290	***	0.060
18 power outages	-0.304	***	0.063	-0.405	***	0.070	-0.345	***	0.060
Duration of **unplanned** power outages (baseline = 10):									
15 hours	-0.247	***	0.061	-0.191	***	0.069	-0.109	*	0.059
18 hours	-0.366	***	0.064	-0.274	***	0.070	-0.291	***	0.061
Decrease in electricity bill	0.069	***	0.004	0.054	***	0.004	0.075	***	0.004
Number of observations	5200			5190			5290		
Number of parameters	33			33			33		
Log Likelihood	-4717.371			-4036.94			-4993.57		
AIC	9500.742			8139.881			10053.139		
BIC	9717.103			8356.179			10270.067		

Source: own elaboration

To further relax the assumption of homogeneous preferences, we explore heterogeneous preferences by running Random Parameters Logit (RPL) models. The first set of RPL models (Tables 16 and 17) include only the attribute levels used in the DCE questions, while the second set also includes interaction terms between the duration and the number of unplanned outages (Tables 18 and 19). The models were estimated using 500 Halton draws, assuming normal distributions for the spread of all the coefficients, except for price which was assumed to be lognormally distributed.

The RPL WTP models confirm the findings of the MNL models, that is, respondents in EE and NL are WTP an increase in their electricity bill to reduce the number of planned power outages from 4 to 2, and from 4 to 3 in PT. We find some evidence of heterogeneous preferences for this attribute only for respondents in NL, where we notice that a large proportion of respondents are actually not willing to pay for a reduction in the number of planned outages.

Respondents are also WTP for a reduction in the duration of planned power outages, and are willing to pay more to benefit from shorter power outages. The larger the improvement in duration of the planned power outages and the larger is also the heterogeneity in preferences in EE and PT.

Respondents value more a reduction in the number of unplanned than planned power outages in all countries. Furthermore, we in EE find that respondents have clear preferences centred around the mean of the coefficient estimates for the duration of unplanned power outages. In NL and PT we find evidence of heterogeneous preferences only for a larger improvement in the number of unplanned power outages.

Table 16. Estimation of Random Parameters Models (RPL), WTP data

	Estonia						Netherlands						Portugal					
	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err	St. Dev.		Rob. St. Err.
ASC1 (Alternative 1)	0.086		0.055				-0.200	***	0.058				0.018		0.056			
ASC3 (Status Quo)	-0.927	***	0.114				-0.596	***	0.113				-0.694	***	0.113			
Random Parameters																		
Normal distribution:																		
Number of **planned** power outages (baseline = 4):																		
3 power outages	0.069		0.067	0.016		0.135	0.089		0.073	0.524	***	0.151	0.125	*	0.064	0.134		0.174
2 power outages	0.185	***	0.069	0.266		0.207	0.150	**	0.069	0.415	***	0.155	0.216	***	0.066	0.047		0.138
Duration of **planned** power outages (baseline = 10 hours):																		
5 hours	0.325	***	0.067	0.146		0.178	0.352	***	0.074	0.567	***	0.176	0.335	***	0.068	0.306		0.296
2 hours	0.520	***	0.067	0.450	***	0.153	0.880	***	0.074	0.290	*	0.176	0.627	***	0.062	0.709	***	0.123
Number of **unplanned** power outages (baseline = 10):																		
5 power outages	0.361	***	0.076	0.599	***	0.179	0.572	***	0.081	0.626	***	0.187	0.223	***	0.072	0.447	*	0.229
2 power outages	0.592	***	0.081	0.815	***	0.196	0.564	***	0.081	0.740	***	0.204	0.255	***	0.081	0.925	***	0.179
Duration of **unplanned** power outages (baseline = 10):																		
5 hours	0.602	***	0.085	0.020		0.114	0.588	***	0.087	0.336		0.209	0.664	***	0.084	0.210		0.323
2 hours	0.811	***	0.085	0.283		0.437	0.909	***	0.090	0.553	***	0.157	0.926	***	0.086	0.416	***	0.155
Log-normal distribution:																		
Increase in electricity bill	-0.881	***	0.094	2.460	***	0.105	-1.390	***	0.145	3.380	***	0.183	-1.110	***	0.117	2.770	***	0.133
Number of Halton Draws	500						500						500					
Observations	5200						5190						5290					
Participants	1040						1038						1058					
Log Likelihood	-4033.805						-4102.667						-4237.246					
AIC	8107.609						8245.334						8514.492					
BIC	8238.737						8376.424						8645.964					

Source: own elaboration

Moving our attention to the RPL model for the WTA data, we notice that respondents are less willing to choose scenarios with a higher number of planned power outages, but we also find evidence of heterogeneous preferences, with some respondents greatly disliking an increase in power outages and others not minding them very much. This trend of large variation in the preferences for the attributes of the DCE questions is confirmed in all the other attributes. This result seems to suggest that while with WTP DCE questions respondents tend to have more precise and similar preferences, with WTA DCE questions, respondents' preferences become more dispersed around the mean, and, therefore, for it becomes more difficult to use the WTA model for policy recommendations.

Table 17. Estimation of Random Parameters Models (RPL), WTA data

	Estonia						Netherlands						Portugal					
	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err	St. Dev.		Rob. St. Err.
ASC1 (Alternative 1)	-0.651	***	0.121				-0.588	***	0.121				-0.462	***	0.114			
ASC3 (Status Quo)	0.482	***	0.128				0.880	***	0.132				0.385	***	0.125			
Random Parameters																		
Normal distribution:																		
Number of **planned** power outages (baseline = 4):																		
5 power outages	-0.303		0.259	0.725		1.570	-0.644	***	0.149	1.310	***	0.226	-0.389	***	0.126	0.964	***	0.343
6 power outages	-1.340	***	0.221	1.770	***	0.390	-1.470	***	0.207	2.190	***	0.238	-1.490	***	0.192	1.820	***	0.227
Duration of **planned** power outages (baseline = 10 hours):																		
15 hours	-1.090	***	0.210	1.840	***	0.254	-0.773	***	0.167	1.170	***	0.325	-1.180	***	0.162	1.410	***	0.249
18 hours	-1.090	***	0.177	1.610	***	0.271	-1.090	***	0.175	1.560	***	0.268	-1.100	***	0.150	1.260	***	0.262
Number of **unplanned** power outages (baseline = 10):																		
15 power outages	-0.754	***	0.147	1.200	***	0.320	-1.010	***	0.170	1.110	***	0.320	-0.932	***	0.124	1.330	***	0.216
18 power outages	-1.060	***	0.200	1.510	***	0.270	-1.290	***	0.193	1.840	***	0.254	-1.410	***	0.173	2.030	***	0.233
Duration of **unplanned** power outages (baseline = 10):																		
15 hours	-1.020	***	0.184	1.990	***	0.235	-0.759	***	0.181	1.650	***	0.294	-0.690	***	0.137	1.950	***	0.185
18 hours	-1.100	***	0.166	1.540	***	0.197	-1.010	***	0.164	1.470	***	0.243	-0.940	***	0.154	1.430	***	0.279
Log-normal distribution:																		
Decrease in electricity bill	-3.660	***	0.370	2.520	***	0.190	-4.300	***	0.324	2.740	***	0.428	-3.630	***	0.276	3.120	***	0.261
Number of Halton Draws	500						500						500					
Observations	5200						5190						5290					
Participants	1040						1038						1058					
Log Likelihood	-3926.745						-3487.147						-3924.078					
AIC	7893.491						7014.294						7888.157					
BIC	8024.619						7145.384						8019.628					

Source: own elaboration

The RPL models with interaction terms show that, for both WTP and WTA data, only a few of the interaction terms are statistically significant. In addition, while for the WTP model there are few estimates for the standard deviation of the coefficients that are statistically significant, for the WTA data, we find a stronger evidence of heterogeneous preferences. In this latest model, all the standard deviations for the levels of the attributes are statistically significant, except for an increase by 1 in the number of planned power outages which is not statistically significant for EE and PT.

The WTP models confirm the finding of the MNL models: people prefer a more reliable service, with a lower number and a shorter duration of power outages in all countries. We also find that the duration of unplanned power outages is valued more than the duration of planned power outages, in all countries. We further find that the coefficient estimate for the current situation (ASC 3 (Status Quo)) is estimated with a negative and statistically significant sign for all countries. This result indicates that people prefer to avoid the current situation and prefers an alternative scenario with improved electricity services, everything else being equal.

The WTA model results for the RPL model with interaction terms shows that people prefer the current situation to a deterioration of the service, as shown by the positive and statistically significant coefficient estimate for ASC3 (Status Quo). We further find that people dislike scenarios characterized by an increased number and duration of planned and unplanned power outages, but we also find a large heterogeneity in preferences across respondents, as shown by the large and statistically significant standard deviations for all the attribute levels. This result confirms that when using WTA there is a much wider distribution of values compared to using WTP which provides a narrower range of values, and therefore a more informative value to use for policy recommendations.

Table 18. Estimation of Random Parameter Logit (RPL) with interaction terms, WTP data

	Estonia						Netherlands						Portugal					
	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err	St. Dev.		Rob. St. Err.
ASC1 (Alternative 1)	0.079		0.068				-0.236	***	0.081				0.024		0.072			
ASC3 (Status Quo)	-0.869	***	0.133				-0.513	***	0.137				-0.468	***	0.134			
Random Parameters																		
Normal distribution:																		
Number of **planned** power outages (baseline = 4):																		
3 power outages	0.108		0.074	0.038		0.041	0.149	*	0.083	0.433	*	0.244	0.157	**	0.069	0.006		0.042
2 power outages	0.233	***	0.076	0.175		0.381	0.204	**	0.083	0.470	**	0.227	0.292	***	0.075	0.003		0.061
Duration of **planned** power outages (baseline = 10 hours):																		
5 hours	0.323	***	0.071	0.182		0.358	0.356	***	0.087	0.838	***	0.194	0.368	***	0.074	0.447	**	0.202
2 hours	0.520	***	0.068	0.440	**	0.175	0.955	***	0.092	0.360		0.282	0.691	***	0.069	0.747	***	0.134
Number of **unplanned** power outages (baseline = 10):																		
5 power outages	0.275	**	0.139	0.375		0.294	0.585	***	0.157	0.461		0.341	0.469	***	0.146	0.305		0.255
2 power outages	0.872	***	0.149	0.957	***	0.182	0.879	***	0.158	0.980	***	0.202	0.725	***	0.151	1.080	***	0.165
Duration of **unplanned** power outages (baseline = 10):																		
5 hours	0.712	***	0.139	0.024		0.083	0.740	***	0.145	0.307		0.301	0.908	***	0.140	0.230		0.373
2 hours	0.814	***	0.148	0.053		0.089	0.946	***	0.153	0.216		0.396	1.290	***	0.150	0.123		0.135
Interactions for **unplanned** outage																		
5 outages & 5 hours	0.235		0.202	0.214		0.276	0.063		0.231	1.080	**	0.462	-0.253		0.225	0.697		0.480
5 outages & 2 hours	0.081		0.215	1.480	***	0.254	0.232		0.254	2.320	***	0.455	-0.302		0.229	1.590	***	0.259
2 outages & 5 hours	-0.834	***	0.210	0.130		0.295	-0.678	***	0.218	0.147		0.345	-0.564	***	0.210	0.121		0.610
2 outages & 2 hours	-0.124		0.208	0.138		0.687	-0.156		0.227	0.447		0.826	-0.753	***	0.219	0.021		0.043
Log-normal distribution:																		
Increase in electricity bill	-0.860	***	0.099	2.480	***	0.108	1.390	***	0.136	3.410	***	0.193	-1.070	***	0.110	2.740	***	0.129
Number of Halton Draws	5000						5000						5000					
Observations	5200						5190						5290					
Participants	1040						1038						1058					
Log Likelihood	-4010.213						-4077.8						-4218.502					
AIC	8076.426						8211.601						8493.005					

Source: own elaboration

Table 19. Estimation of Random Parameter Logit (RPL) with interaction terms, WTA data

	Estonia						Netherlands						Portugal					
	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err.	St. Dev.		Rob. St. Err.	Mean		Rob. St. Err	St. Dev.		Rob. St. Err.
ASC1 (Alternative 1)	-0.652	***	0.130				-0.709	***	0.145				-0.537	***	0.130			
ASC3 (Status Quo)	0.487	***	0.139				0.844	***	0.142				0.400	***	0.134			
Random Parameters																		
Normal distribution:																		
Number of **planned** power outages (baseline = 4):																		
5 power outages	-0.330	**	0.167	0.801		0.531	-0.603	***	0.145	1.280	***	0.218	-0.307	*	0.157	0.485		0.968
6 power outages	-1.370	***	0.186	1.940	***	0.282	-1.780	***	0.316	2.640	***	0.357	-1.430	***	0.203	1.740	***	0.271
Duration of **planned** power outages (baseline = 10 hours):																		
15 hours	-1.300	***	0.232	2.330	***	0.376	-1.080	***	0.186	1.850	***	0.270	-1.480	***	0.246	2.100	***	0.376
18 hours	-1.070	***	0.205	1.670	***	0.401	-1.710	***	0.282	2.520	***	0.313	-1.290	***	0.210	1.590	***	0.312
Number of **unplanned** power outages (baseline = 10):																		
15 power outages	-0.798	***	0.228	1.360	***	0.368	-0.911	***	0.271	0.797	*	0.441	-0.930	***	0.230	1.550	***	0.266
18 power outages	-1.380	***	0.245	1.890	***	0.328	-1.740	***	0.313	2.130	***	0.321	-1.730	***	0.257	2.360	***	0.393
Duration of **unplanned** power outages (baseline = 10):																		
15 hours	-1.190	***	0.240	1.980	***	0.230	-0.755	***	0.226	1.530	***	0.224	-0.596	***	0.216	1.720	***	0.215
18 hours	-1.060	***	0.225	1.390	***	0.361	-1.000	***	0.236	1.150	***	0.357	-1.190	***	0.253	1.560	***	0.284
Interactions for **unplanned** outage																		
15 outages & 15 hours	0.039		0.322	0.391		0.586	-0.406		0.521	1.250		0.802	-0.187		0.315	0.120		0.565
15 outages & 18 hours	-1.370	***	0.487	2.940	***	0.551	-0.425		0.459	1.850	***	0.596	-1.780	***	0.633	3.860	***	0.740
18 outages & 15 hours	0.340		0.350	1.380	***	0.363	0.301		0.522	1.280	*	0.760	-0.119		0.484	2.080	**	0.837
18 outages & 18 hours	-0.335		0.681	1.550		1.220	-0.063		0.416	1.610	***	0.519	-0.243		0.397	2.400	***	0.613
Log-normal distribution:																		
Decrease in electricity bill	-3.360	***	0.293	2.530	***	0.216	-4.380	***	0.296	2.940	***	0.280	-3.280	***	0.266	3.350	***	0.283
Number of Halton Draws	500						500						500					
Observations	5200						5190						5290					
Participants	1040						1038						1058					
Log Likelihood	-3903.301						-3462.547						-3906.873					
AIC	7862.603						6981.095						7869.746					
BIC	8046.183						7164.62						8053.806					

Source: own elaboration

We use the output from the RPL WTA and RPL WTP models (without interactions) to estimate respondents' WTP and WTA for selected scenarios. For the "best scenario" (least number of power outages and the shortest duration) the WTP is on average €5.09 in EE, €10.05 in NL and €6.14 in PT. There is a large unobserved heterogeneity in WTP captured by the estimates of the standard deviation. In particular, for NL we observe that respondents' WTP is not well centred around the mean, instead it is well spread out. The reduction of one planned power outage is valued at €0.17 in EE, €0.36 in NL, and €0.38 in PT. A reduction in 5 hours of planned power outages is worth €0.78 in EE, €1.41 in NL and €1.02 PT. An identical reduction in unplanned power outages is worth €1.45 in EE, €2.36 in NL and €2.01 in PT.

When considering a reduction in the quality of the provision of electricity, we find that respondents have very high (mean) WTA values, indicating that a deterioration to the service is particularly undesirable. For the "worst case scenario" (largest number of power outages and longest duration) the mean WTA is €178.37 in EE, €358.18 in NL and €186.30 in PT. We also notice a large spread in WTA values, as shown by the standard deviation values, as some respondents have very high WTA values and others very low (see Table 19).

Table 20. Welfare changes from WTP and WTA scenarios

WTP (€/year):	Estonia				Netherlands				Portugal			
	WTP	St. Err.	St. Dev.	St. Err.	WTP	St. Err.	St. Dev.	St. Err.	WTP	St. Err.	St. Dev.	St. Err.
The "best" scenario (the least number of power outages and the shortest duration):	5.09	0.56	12.75	1.33	10.05	1.46	34.23	2.27	6.14	0.78	17.42	1.29
The "best" scenario for only the **planned** outages (the least number of outages and shortest duration):	1.70	0.26	4.37	0.65	4.14	0.66	14.12	1.18	2.56	0.37	7.41	0.67
The "best" scenario for only the **unplanned** outages (the least number of outages and shortest duration):	3.39	0.41	8.59	1.17	5.91	0.92	20.33	1.45	3.58	0.52	10.39	0.86
1 **planned** power outage **reduction** (from 4 to 3):	0.17	0.16	0.41	0.33	0.36	0.29	2.42	0.61	0.38	0.20	1.13	0.53
5 hour **decrease** of **planned** outage (from 10h to 5h):	0.78	0.17	1.96	0.43	1.41	0.35	5.29	0.73	1.02	0.23	2.96	0.91
5 **unplanned** power outage **reduction** (from 10 to 5):	0.87	0.19	2.59	0.44	2.30	0.43	8.16	0.84	0.68	0.23	2.31	0.70
5 hour **decrease** of **unplanned** outage (from 10h to 5h):	1.45	0.24	3.57	0.31	2.36	0.47	8.09	0.95	2.01	0.33	5.62	1.01
WTA (€/year):	**Estonia**				**Netherlands**				**Portugal**			
	WTA	St. Err.	St. Dev.	St. Err.	WTA	St. Err.	St. Dev.	St. Err.	WTA	St. Err.	St. Dev.	St. Err.
The "worst" scenario (the highest number of power outages and the longest duration):	178.37	66.19	466.61	40.42	358.18	114.20	1016.16	157.47	186.30	51.35	594.64	51.49
The "worst" scenario for only the **planned** outages (the highest number of outages and longest duration):	94.43	36.24	255.49	25.04	188.67	62.87	553.64	86.14	97.68	28.08	315.98	28.80
The "worst" scenario for only the **unplanned** outages (the highest number of outages and longest duration):	83.94	31.60	227.53	20.86	169.51	54.63	495.83	75.55	88.63	24.92	291.94	26.30
1 **planned** power outage **increase** (from 4 to 5):	11.77	11.01	40.92	61.08	47.46	18.91	161.97	27.00	14.67	6.40	58.45	13.68
5 hour **increase** of **planned** outage (from 10h to 15h):	42.36	17.09	128.48	12.74	56.97	21.55	178.33	35.27	44.50	12.89	148.68	14.81
5 **unplanned** power outage **increase** (from 10 to 15):	29.30	12.43	87.33	14.03	74.44	26.12	219.75	38.31	35.15	10.20	120.59	12.02
5 hour **increase** of **unplanned** outage (from 10h to 15h):	39.64	16.62	126.33	12.21	55.94	22.45	195.65	31.54	26.02	8.59	109.54	9.69

Source: own elaboration

4.1 Value per unit of energy unserved

Based on the results, we estimate the WTP to avoid a one hour power outage, and the WTA for accepting it (Table 21). In EE the WTP is between €0.15 and €0.29, while the WTA is between €7.92 and €8.47. For NL, the WTP is between €0.28 and €0.47 and the WTA is about €11. In PT, the WTP is between €0.20 and €0.40, and the WTA is between €5.20 and €8.90.

The values of the VoLL are presented in Table 21.

Table 21. Values of €/hour of power outage

		Estonia	the Netherlands	Portugal
Planned power outage	WTP	0.15	0.28	0.20
Unplanned power outage	WTP	0.29	0.47	0.40
Planned power outage	WTA	8.47	11.39	8.90
Unplanned power outage	WTA	7.92	11.18	5.20

Source: own elaboration

The next step is to convert the VoLL monetary values per outage estimates into €/kWh. For this conversion, we obtain from Eurostat the estimates of electricity consumption for, divide by the population size, and then convert into an hourly figure. In particular, in 2016, the households' electricity consumption was 5,099 GWh in EE, 68,017 GWh in NL and 30,885 GWh in PT.[5] The populations were: 1.316 million in EE, 17.02 million in NL and 10.32 million in PT. Thus, electricity consumption in MWh/person per year was 3.8746 MWh in EE, 3.99 MWh in NL and 2.99 MWh in PT.

[5] http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00094&language=en

The above values correspond to an average consumption of 0.44 kWh, 0.45 kWh and 0.34 kWh per person per hour in EE, NL and PT respectively. To estimate the VoLL we divide the values obtained in Table 21 by the kWh consumed in one hour. The results (Table 22) show that respondents should be at least WTP pay €0.34 for one extra kWh in EE, €0.61 in NL and €0.59 in PT, while for reducing their consumption by 1 kWh they should be WTA no less than €17.91 in EE, €24.51 in NL and €15.22 in PT.

Table 22. Value of Lost Load (VoLL) in €/kWh for the three countries

		Estonia	the Netherlands	Portugal
Planned power outage	WTP	0.34	0.61	0.59
Unplanned power outage	WTP	0.66	1.03	1.17
Planned power outage	WTA	19.15	24.97	26.05
Unplanned power outage	WTA	17.91	24.51	15.22

Source: own elaboration

Therefore, gains and losses of electricity supply are not perceived in a symmetric way, which is consistent with economic and behavioural studies (especially Kahnemann and Tversky, 1979). However, our study provides novel empirical evidence in stated preference analysis of the value of power outages. This exercise explicitly modelled the change in utility associated either with higher or lower level of power outages with respect to the baseline of the status quo. One DCE offers the WTP (e.g.) for investments to improve the continuity of supply, and a second one the WTA a compensation for suffering more outages. For EE, the value of improved security of supply arising from reducing power outages by 1 kWh is estimated to be €0.66. The correspondent value for NL is higher (€1.03) while the largest value is found for PT (€1.17). These values capture directly the way consumers value the benefit of improving the quality of the service: they indicate how much consumers are willing to pay to receive additional continuity of power supply.

The WTA experiment elicits the minimum compensation the consumer accepts for the inconveniences from additional unplanned blackouts with respect to the baseline of the current continuity of electricity supply. This provides values that are substantially higher than the ones found for WTP. In EE, a kilowatt-hour lost is worth €17.91, €24.51 in NL, and €15.22 in PT. Table 17 provides a comparison of our results with other studies.

These WTP and WTA values can then be used by policymakers to decide on future investments in the reliability of power supply. The WTP values should be compared with the costs of a 1 kWh/person per year improvement. The WTA values should be used whether the policymaker prefers to not invest in improvements to the network, and compensate households for future losses of power supply.

Table 23. Comparison of the survey results with other available studies (€/kWh)

Survey	Study context	Sector	€/kWh
Fischer (1986)	USA, summer, afternoon	Trade	23.00
Woo & Gray (1987)	USA, summer, afternoon	Industry	79.30
Woo & Train (1988)	USA, summer, afternoon	Trade	11.30
Caves et al. (1990)	USA (maximum value)	Firms	29.80
Doane et al. (1990)	USA, winter, evening	Industry	8.90
Sullivan et al. (1996)	USA	Firms	50.80
Bertazzi et al. (2005)	Italy	Firms	143.90
Bliem (2007)	Austria	Firms	239.30
Reichl et al. (2007)	Austria	Firms	8.60
De Nooij et al. (2007)*	Netherlands	Non-household consumers	21.20
Reichl et al, 2013	Austria, winter, morning	Non-household consumers	29.70
Doane et al. (1988)***	USA, winter, evening	Households	22.20
Sanghvi, (1983)	USA, summer, midday	Households	0.20
Bertazzi et al. (2005)	Italy	Households (WTA) Households (WTP)	20.96 4.61
(Abrate, Bruno, Erbetta, Fraquelli, & Lorite-Espejo, 2016)	Italy	Households (WTA)	25.37
Fickert (2004)	Austria	Households	2.40
Bliem (2007)	Austria	Households	6.20
Reichl et al. (2007)	Austria	Households	3.90
Reichl et al, 2013	Austria, winter, morning	Households	2.80
(Hoch & James, 2011)	Australia	Households (consumption weighted average)	34.74
(Küfeoglu & Lehtonen, 2015)	Finland	Household	65.88
(Growitsch, Malischek, Nick, & Wetzel, 2013)	Germany	Households	12.06
(Piaszeck, Wenzel, & Wolf, 2013)	Germany	Households	13.44
(Praktiknjo A. J., 2014)	Germany	Households	10.53
Our study	Estonia	Households (WTA)	17.91
Our study	the Nethlerlands	Households (WTA)	24.51
Our study	Portugal	Households (WTA)	15.22

Source: own elaborations on Reichl et al. 2013

5 Discussion and conclusion

The Value of Lost Load (VoLL) is an economic measure of the perceived damages caused by power outages. Its value is a proxy of the costs of the disruptions, in terms of losses of energy services experienced by customers. It differs across residential customers and firms across different sectors of the economy. The first part of the study recalls the concept of Customer Damage Function, defining the damage value per unit of energy unserved, as a measure of the value of the security of electricity supply. For short and momentary blackouts, the main evaluation techniques applied to this framework were illustrated in Section 2 providing insights on the advantages and disadvantages of the different methodologies.

For this study, we designed an ad-hoc evaluation exercise based on stated preferences to assess households' WTPs and WTAs as metrics for the VoLL. Section 3 illustrated the methodology of the Discrete Choice Experiments (DCEs), the econometric models used to develop the case studies for Estonia, the Netherlands and Portugal.

Results from two different DCE exercises, one aimed at estimating the WTP and one for assessing the WTA were described in Section 4, where we summarized the results obtained from the econometric analysis.

This exercise explicitly modelled the change in utility associated either with higher or lower durations of power outages, with respect to the baseline of the status quo. One DCE investigates the WTP for investments to improve the continuity of supply, and a second one the WTA compensation for accepting a deterioration of the actual performance of electricity supply in terms of power outages. In line with the results of existing stated preferences studies, we can observe that gaining continuity through a reduction of blackouts, or a symmetric loss in continuity do not lead to the same monetary amounts. Endowment effects and loss aversion described by the prospect theory of Kahneman and Tversky (Kahneman & Tversky, 1979) explain why the WTA exercise provides much higher values than the corresponding one for WTP.

For EE, the value of improved security of supply arising from reducing by 1 kWh the unserved electricity is €0.66. The correspondent value for NL is €1.03, and an even higher value is assessed by households in PT (€1.17). These values capture directly the way consumers value the benefit of improving the quality of the service; these values express the effort they are willing to make to receive additional continuity of power supply. The experiment on WTA elicits the minimum compensation the consumer accepts for the inconveniences from additional blackouts with respect to the baseline of the current continuity of electricity supply. This provides values that are substantially higher than the previous ones estimated using the WTP framework. WTA values are a valid proxy of the damage value and another recent DCE study (London Economics, 2013) has privileged as well the WTA framework, as more comprehensive assessment of damages. A substantial concern for any loss in reliability is pointed out from the results of the WTA exercises. For EE, an additional unplanned loss of a kWh was priced by respondents €17.91, €24.51 for NL and €15.22 for PT.

Two approaches were adopted to further explore the heterogeneity in preferences in the DCEs. Firstly, a set of characteristics of respondents was entered as interactions with alternative specific constants in the MNL basic specifications, to verify improvements in the explanatory power of the models. Secondly, random parameters models were estimated, estimating parameters of distributions instead of point value estimates for the attributes of the utility function. This determined whether the importance of one attribute of the alternatives converges to the same point value or it is rather dispersed. The RPL models revealed how the preferences in terms of WTA and WTP are dispersed around the mean estimates, giving evidence of a notable heterogeneity in the way consumers consider the importance of continuity of power supply.

Factors explaining the variability of responses both in the WTA and WTP DCEs include:

- *socio-economic variables:* (age and income)
- *previous experience of prolonged power cuts*
- *orientation toward long term strategies for the EU energy security*
- *personal values*

These factors exhibit some statistical significance, without adding a substantial increase in the explanatory power and goodness of fit of the model. More heterogeneity in preferences has been explained with the use of the RPL estimator.

In providing two sets of values for the VoLL, we suggest that the perceived damage from losses in continuity keeps properly into account that WTA base estimates represent a hypothetical circumstance where the consumer accepts a reduction in continuity.

The results offer information, suitable for policy support. VoLL estimate can find application in:

- informing problems of cross-border cost allocation of energy infrastructures. Whenever investment in interconnection capacities among countries provide potentially asymmetric benefits, the VoLL, can play a key role in determining the costs and benefits from avoided blackouts to different parties.
- the ex-ante evaluation of investments in energy networks (e.g. transmission lines). WTP based results can be used to inform cost-benefit analyses, as proxy of the avoided damage can be used to represent benefits of increased continuity. Reduced outages in energy to be multiplied by the value €/kWh for the average benefit for household, then aggregated over the population interested by the improvement.
- defining monetary compensations for damages occurred to residential electricity customers in case of outages from malfunctioning of the networks, whenever the energy retailers, or the Distribution System Operator(s), must compensate for the inconveniences caused by power cuts, especially for interruptible contracts.
- setting maximum caps to electricity prices. Pricing bounds, or caps, e.g. indicators of maximum willingness-to -pay reflecting perceived damage, beyond which it is more convenient to suffer the damage

In this study we explored the application of DCEs. A forthcoming study (volume 4 of the SASOS project) will develop a comparative assessment of the different results obtained by different variations of the stated preferences approach, from a survey to both industrial commercial and small medium enterprises and residential customers.

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List of abbreviations and definitions

AIC	Akaike Information Criteria
ASCs	Alternative Specific Constants
BIC	Bayesian Information Criteria
CASES	Cost Assessment of Sustainable Energy Systems
CV	Contingent Valuation
CDF	Customer Damage Function
CU	Current Situation
DCE	Discrete Choice Experiment
EE	Estonia
ENS	Energy Not Served, or alternatively Energy Not Supplied
GDP	Gross Domestic Product
IEAR	Interrupted Energy Assessment Rate
kW	kilowatt
kWh	kilowatt-hour
LL	Log likelihood function
MLE	Maximum Likelihood Estimator
MNL	Multinomial Logit Model
MWh	megawatt hour
NL	the Netherlands
PT	Portugal
RPL	Random Parameter Logit
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
WTA	Willingness-to-accept
WTP	Willingness-to-pay
VoLL	Value of Lost Load

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Annex A: Questionnaire to households

Socio-demographics: this section is a generic example which is then adapted to the specific country with the help of local experts, e.g. the classes of age or family size should fit the classification of national statistics if used for checking the match between the structure of the population and the one of the sample.

Section A: the respondent

Please tell us about yourself:

1. Level of education:

   - ☐ Postgraduate
   - ☐ Graduate
   - ☐ Undergraduate
   - ☐ Secondary
   - ☐ Other

2. Age: __ years old
3. Gender:

   - ☐ Male
   - ☐ female

4. Job role: ____________________
5. How many people live in your household including you?

   What is the age composition of the household?

Member 1 :	☐ 0-18	☐ 19-30	☐ 31-45	☐ 46-60	☐ Over 60
Member 2 :	☐ 0-18	☐ 19-30	☐ 31-45	☐ 46-60	☐ Over 60
Member 3 :	☐ 0-18	☐ 19-30	☐ 31-45	☐ 46-60	☐ Over 60
Member 4 :	☐ 0-18	☐ 19-30	☐ 31-45	☐ 46-60	☐ Over 60
Member 5 :	☐ 0-18	☐ 19-30	☐ 31-45	☐ 46-60	☐ Over 60

Section B – Personal values

1. Below you will find brief descriptions of different persons. For each person we describe what is very important to [him/her]. Please read each description carefully and indicate how much this person is like you. The meaning of the scores is as follows: 1 means that the person is entirely not like you, 7 means that the person is entirely like you.

Try to distinguish as much as possible in your answering by using different scores. The person that is most like you should thus receive the highest score. The person that is the least like you, the lowest.	**Entirely not like me**						**Entirely like me**
a) It is important to [him/her] that every person has equal opportunities.	1	2	3	4	5	6	7
b) It is important to [him/her] that every person is treated justly.	1	2	3	4	5	6	7
c) It is important to [him/her] to take care of those who are worse off.	1	2	3	4	5	6	7
d) It is important to [him/her] that there is no war or conflict.	1	2	3	4	5	6	7
e) It is important to [him/her] to be helpful to others.	1	2	3	4	5	6	7
f) It is important to [him/her] to protect the environment.	1	2	3	4	5	6	7
g) It is important to [him/her] to be in unity with nature.	1	2	3	4	5	6	7
h) It is important to [him/her] to respect nature.	1	2	3	4	5	6	7
i) It is important to [him/her] to prevent environmental pollution.	1	2	3	4	5	6	7
j) It is important to [him/her] to have fun.	1	2	3	4	5	6	7
k) It is important to [him/her] to enjoy the life's pleasures.	1	2	3	4	5	6	7
l) It is important to [him/her] to do things [he/she] enjoys.	1	2	3	4	5	6	7
m) It is important to [him/her] to be influential.	1	2	3	4	5	6	7
n) It is important to [him/her] to have control over others' actions.	1	2	3	4	5	6	7
o) It is important to [him/her] to have authority over others.	1	2	3	4	5	6	7
p) It is important to [him/her] to work hard and be ambitious.	1	2	3	4	5	6	7
q) It is important to [him/her] to have money and possessions.	1	2	3	4	5	6	7

Thinking about energy security for your country of residence in the next five years you, how important it is <u>for you...</u>	Extremely unimportant	Somewhat unimportant	Neither important nor unimportant	Somewhat important	Extremely important
...To have a **secure supply of oil, gas, coal and uranium**	☐	☐	☐	☐	☐
...To promote **trade** in energy products, technologies, and exports	☐	☐	☐	☐	☐
...to **minimize depletion** of domestically available energy fuels	☐	☐	☐	☐	☐
...to **have stable, predictable, and clear** price signals	☐	☐	☐	☐	☐
...to have **affordably priced energy services**	☐	☐	☐	☐	☐
...to have **small scale, decentralized** energy systems	☐	☐	☐	☐	☐
...to have a **low energy intensity** (unit of energy required for unit of economic output)	☐	☐	☐	☐	☐
...to conduct **research and development** an new and innovative energy technologies	☐	☐	☐	☐	☐
...to assure **equitable access** to energy services to all its citizens	☐	☐	☐	☐	☐
...to ensure **transparency and participation** in energy permitting, siting and decision making	☐	☐	☐	☐	☐
...to inform consumers and promote social and community **education** about energy issues	☐	☐	☐	☐	☐
...to minimize the destruction of forests and the degradation of **land** and soil	☐	☐	☐	☐	☐
...to provide available and clean **water**	☐	☐	☐	☐	☐
...to minimize **air pollution**	☐	☐	☐	☐	☐
...To minimize the impact of **climate change** (i.e. adaptation)	☐	☐	☐	☐	☐
...to reduce the **greenhouse gas emissions** (i.e. mitigation)	☐	☐	☐	☐	☐

18. Given the sixteen dimensions of energy security discussed here, select the five that you think are the most important for your country of residence, and rank them from 1 (the most important) to 5 (5th most important), without allowing for ties. Please rank only 5 dimensions

☐	Secure supply of oil, gas, coal, and uranium	☐	Equitable access
☐	Bolstering trade	☐	Transparency and participation in siting and decision making
☐	Minimizing rate of depletion	☐	Education and information
☐	Predictable and clear price signals	☐	Preservation of land
☐	Affordably priced energy services	☐	Availability and quality of water
☐	Decentralization and small scale supply	☐	Minimal air pollution
☐	Low energy intensity	☐	Responding to climate change (adaptation)
☐	Research and development	☐	Reducing greenhouse gas emission (mitigation)

19. Did we miss any dimension that you consider important for the energy security of your country of residence in the next five years? Please enter below:

____

I don’t miss anything <go to Q21>

<show Q20 on same page as Q19 in case respondents mentioned something in the open text box at Q19>

20. ~~If you did provide an answer,~~ When you think about energy security for your country of residence in the next five years, how important s the above dimension?

☐ Extremely important

☐ Somewhat important

☐ Neither important nor unimportant

☐ Somewhat unimportant

☐ Extremely unimportant

Section B - Household energy use, expenditures and perceived risks of damages from power cuts

21. **Which of the following options best describes the area where you live?**

☐ A big city

☐ The suburbs or outskirts of a big city

☐ A town or a small city

☐ A country village

☐ A farm or home in the countryside

22. **What is approximately the size of your house (excluding garages attic and basement)?**

___________________ square meters

23. **Please indicate whether you own or you intend to purchase the following:**

	I have this	I do not have this but I intend to buy it in the near future	I do not have this and have no intend of buying it in the near future	I do not know
Solar panels for electricity	☐	☐	☐	☐
Electric/hybrid car	☐	☐	☐	☐
Solar panels for heating water	☐	☐	☐	☐
Woodchip heaters	☐	☐	☐	☐
Micro wind generator	☐	☐	☐	☐
Smart meters	☐	☐	☐	☐
Applications to automatize operation of electric appliances at home	☐	☐	☐	☐

24. **Which is the main fuel you use in your home to**

	Electricity	Gas	Wood	Other (specify)
Heat the house	☐	☐	☐	☐
Cook	☐	☐	☐	☐
Heat the water	☐	☐	☐	☐

25. **Which of the following activities cannot be done in your house <u>in any way</u>, if electricity is not available (in case you use gas to heat your home, heating is likely to stop as well without electricity)**

☐ Cooking	☐ Warming rooms	☐ Washing dishes
☐ Indoor lighting	☐ Talk on the phone	☐ Washing clothes
☐ Using internet	☐ Having a bath/shower	☐ Cleaning floors
Others:	______________________	____________________

26. **A - Can you estimate how much you pay on a monthly basis for the following utilities?**

<answers are empty allowed>

	euros
Electricity	_____
Gas	_____
Water	_____
Combined gas and electricity	_____
Wood	_____

B - Could you tell when you pay for the following utilities?

< empty answers allowed>

	Monthly	Every two months	Every three months	Every 4 months
Electricity	☐	☐	☐	☐
Gas	☐	☐	☐	☐
Water	☐	☐	☐	☐
Combined gas and electricity	☐	☐	☐	☐
Wood	☐	☐	☐	☐
Other	☐	☐	☐	☐

1) **In case of a power outage ("blackout"), what are the inconveniences that you are more concerned about?**

____ (open question)

Section D: Planned power cuts

Sometimes, the electricity network operator undertakes planned maintenance work on the network. When this happens, they will inform customers in advance of the planned power cut so that customers can adapt their activities accordingly and be prepared for the power cut.

When, if at all, did you last have a planned power cut to your home?

<If the answer is (Q27:1) "In the last 12 months" then go to question Q28. Otherwise go to Q30>

In the last 12 months	1
More than 1 year but less than 5 years ago	2
More than 5 years but less than 10 years ago	3
More than 10 years ago	4
Do not recall having a planned power cut	5
Had had a planned power cut but cannot recall when it took place	6

Thinking about the last 12 months how many times have you experienced a planned power cut?

<If the answer is (Q28:1) "Once" or (Q28:2) "Twice" or (Q28:3)"Three times" or (Q28:4)"More than three times" or (Q28:6)"Not sure" then go to Q29. If the answer is (Q28:5) "Never" go to Q30>

Once	1
Twice	2
Three times	3
More than three times	4
Never	5
Not sure	6

In the last 12 months, what was the longest time you were without power during a planned power cut?

Less than 4 hours	1
More than 4 hours	2
Not sure	3

Section E: Unplanned power cuts

Sometimes the electricity network suffers an unplanned power outage. This may happen because of unpredictable damages, faults in the network. Customers cannot be informed in advance of an unplanned power outage.

When, if at all, did you last have an unplanned power cut to your **home**?

<If the answer is (Q30:1) "In the last 12 months" then go to the Q31. Otherwise go to infoQ33>

In the last 12 months	1
More than 1 year but less than 5 years ago	2
More than 5 years but less than 10 years ago	3
More than 10 years ago	4
Do not recall having a unplanned power cut	5
Had had an unplanned power cut but cannot recall when it took place	6

Thinking about the last 12 months how many times have you experienced an unplanned power cut?

<If the answer is (Q31:1) "Once" or (Q31:2) "Twice" or (Q31:3) "Three times" or (Q31:4) "More than three times" or (Q31:6) "Not sure" then go to Q32. If the answer is (Q31:5) "Never" then go to infoQ33>

Once	1	
Twice	2	
Three times	3	
More than three times	4	____________
Never	5	
Not sure	6	

In the last 12 months, what was the longest time you were without power due to an unplanned power cut?

Up to 1 hour	1
1 to 3 hours	2
3 to 10 hours	3
More than 10 hours – please specify	4

Section F: Hypothetical questions on electricity scenarios

In this section, we will ask you to consider some hypothetical scenarios on power outages.

The most recent data on power outages[6] show that, under the current levels of investments in the electricity network, over the next five years we should expect to have 4 planned power outages lasting 10 hours and 10 unplanned power outages lasting 10 hours.

Suppose that no new investments are made to the electricity network during the next five years. As a result, the number and the duration of both planned and unplanned power outages will increase. Households will be compensated for the inconvenience caused through a reduction in their electricity bill.

You will see now 5 hypothetical choice cards, with each card showing the current situation, and two alternative hypothetical scenarios of power outages in the next 5 years resulting in cost reductions during the same 5 year period. Before choosing your favourite option in each card, consider the effect that an increase in power outages would have on you and the discount on your electricity bill.

27. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	6	4	4
Duration of **planned** power outages in the next 5 years	18 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	10	10	10
Duration of **unplanned** power outages in the next 5 years	15 hours	18 hours	10 hours
Electricity bill	€1 discount on electricity bill per year	€3 discount on electricity bill per year	No change
Which option would you choose?	☐	☐	☐

28. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	6	5	4
Duration of **planned** power outages in the next 5 years	15 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	18	10	10
Duration of **unplanned** power outages in the next 5 years	18 hours	15 hours	10 hours
Electricity bill	€10 discount on electricity bill per year	€3 discount on electricity bill per year	No change
Which option would you choose?	☐	☐	☐

29. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	4	6	4
Duration of **planned** power outages in the next 5 years	10 hours	18 hours	10 hours
Number of **unplanned** power outages in the next 5 years	15	18	10
Duration of **unplanned** power outages in the next 5 years	15 hours	10 hours	10 hours
Electricity bill	€5 discount on electricity bill per year	€20 discount on electricity bill per year	No change
Which option would you choose?	☐	☐	☐

30. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	5	6	4
Duration of **planned** power outages in the next 5 years	18 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	10	15	10
Duration of **unplanned** power outages in the next 5 years	18 hours	10 hours	10 hours
Electricity bill	€5 discount on electricity bill per year	€1 discount on electricity bill per year	No change
Which option would you choose?	☐	☐	☐

31. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	5	4	4
Duration of **planned** power outages in the next 5 years	15 hours	18 hours	10 hours
Number of **unplanned** power outages in the next 5 years	15	10	10
Duration of **unplanned** power outages in the next 5 years	10 hours	15 hours	10 hours
Electricity bill	€20 discount on electricity bill per year	€3 discount on electricity bill per year	No change
Which option would you choose?	☐	☐	☐

Suppose that to reduce the number and duration of power outages, new investments are needed for the electricity network. These investments would have to be funded through an increase in the electricity bill.

I am going to show you 5 hypothetical choice cards showing various options for investment over the next 5 years and associated cost to you. Each card will have the current situation, and two alternative improved options with different costs in the form of an increase in your annual electricity bill. Before choosing your favourite option in each card, consider your household's budget and the impact that your choice would have on your household's budget.

32. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	4	3	4
Duration of **planned** power outages in the next 5 years	5 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	10	2	10
Duration of **unplanned** power outages in the next 5 years	2 hours	2 hours	10 hours
Electricity bill	€20 increase in annual electricity bill	€5 increase in annual electricity bill	No change
Which option would you choose?	☐	☐	☐

33. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	4	3	4
Duration of **planned** power outages in the next 5 years	5 hours	2 hours	10 hours
Number of **unplanned** power outages in the next 5 years	10	5	10
Duration of **unplanned** power outages in the next 5 years	5 hours	5 hours	10 hours
Electricity bill	€3 increase in annual electricity bill	€10 increase in annual electricity bill	No change
Which option would you choose?	☐	☐	☐

34. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	3	2	4
Duration of **planned** power outages in the next 5 years	5 hours	2 hours	10 hours
Number of **unplanned** power outages in the next 5 years	2	10	10
Duration of **unplanned** power outages in the next 5 years	2 hours	10 hours	10 hours
Electricity bill	€1 increase in annual electricity bill	€3 increase in annual electricity bill	No change
Which option would you choose?	☐	☐	☐

35. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	2	4	4
Duration of **planned** power outages in the next 5 years	10 hours	5 hours	10 hours
Number of **unplanned** power outages in the next 5 years	2	5	10
Duration of **unplanned** power outages in the next 5 years	2 hours	2 hours	10 hours
Electricity bill	€20 increase in annual electricity bill	€1 increase in annual electricity bill	No change
Which option would you choose?	☐	☐	☐

36. Choose your preferred option

	Option A	Option B	Current situation
Number of **planned** power outages in the next 5 years	2	3	4
Duration of **planned** power outages in the next 5 years	2 hours	10 hours	10 hours
Number of **unplanned** power outages in the next 5 years	5	5	10
Duration of **unplanned** power outages in the next 5 years	10 hours	2 hours	10 hours
Electricity bill	€5 increase in annual electricity bill	€3 increase in annual electricity bill	No change
Which option would you choose?	☐	☐	☐

Section G: Long term Security of Energy Supply

The European Union (EU) imports more than half of all the energy it consumes. Its import dependency is particularly high for crude oil (more than 90 %) and natural gas (66 %). The total import bill is more than €1 billion per day.

Many countries heavily rely on a single supplier, including some that rely entirely on Russia for their natural gas. This dependence leaves them vulnerable to supply disruptions, whether caused by political or commercial disputes, or infrastructure failure.

37. How important is having reliable and affordable energy supply for the following people? Please tick the box that best represents your view

	Very important	Important	Moderately Important	Slightly Important	Not Important
	1	2	3	4	5
You	☐	☐	☐	☐	☐
Your family	☐	☐	☐	☐	☐
Your country	☐	☐	☐	☐	☐
European Union	☐	☐	☐	☐	☐
Future generations	☐	☐	☐	☐	☐

The EU Energy Security Strategy describes a roadmap to 2030 that EU member states need to follow to increase their energy security, that is, to have more reliable and affordable energy and be less dependent on imports of energy. In particular, the strategy aims to reduce imports of oil by 3 %, gas by 14 % and coal by 12 % compared to the business as usual scenario by 2030. These goals will be achieved by:

- saving energy,
- producing more local renewable energy
- making it easier to transport gas and electricity around Europe,
- finding different ways and routes to import energy,
- building good relationships with suppliers and distributers, and
- having common goals when negotiating with other countries.

The implementation of the strategy will require an increase in energy prices now for EU Member States to be able to undertake all the investments needed for a more reliable and affordable energy in the future. If the strategy is not implemented, sudden prolonged energy disruptions could occur in the future, as well as huge fluctuations in electricity prices.

38. How important do you think it is to increase the reliability and the affordability of energy supply implementing the EU Energy Security Strategy?

Very important	Important	Moderately Important	Slightly Important	Not Important
1	2	3	4	5

Suppose that an **increase in the electricity bill for the next 5 years** was used to fund the EU Energy Security Strategy. You will see higher and a lower increase in the electricity bill and will be asked whether you would be willing to pay it to guarantee the reliability and the affordability of energy until 2030. Before answering, please think carefully about the consequences of paying the increase in the electricity bill as your disposable income for other expenditure would decrease. If you decide that you are not willing to pay, you should consider that if EU Energy Security Strategy would not be implemented, sudden prolonged energy disruptions, as well as huge fluctuations in the price of electricity may occur.

You should present the question 45 treating 25 % of the sample putting the monetary value of 10, 25 % with the value 20, 25 % with 50 and the last 25 % with 100.

In question 46 (not 36 as specified in brackets!) we repeat the request of a willingness-to-pay asking a higher value

If 45 is a YES with a value of 10 euros in 46 you should ask 20 euros

If 45 is a YES with a value of 20 euros in 46 you should ask 50 euros

If 45 is a YES with a value of 50 euros in 46 you should ask 100 euros

If 45 is a YES with a value of 100 euros in 46 you should ask 200 euros

With answer NO to 45 the respondent should always go to 47. Here we ask lower values

If 45 is a NO or Don't know with a value of 10 euros in 47 you should ask 5 euros

If 45 is a NO or Don't know with a value of 20 euros in 47 you should ask 10 euros

If 45 is a NO or Don't know with a value of 50 euros in 47 you should ask 20 euros

If 45 is a NO or Don't know with a value of 100 euros in 47 you should ask 50 euros

39. Would you be willing to support the implementation of the EU Energy Security Strategy to guarantee the reliability and the affordability of energy until 2030 if your annual electricity bill was €[10, 20, 50, 100] more expensive for the next five years?

☐ YES [go to question 46]

☐ NO [go to question 47]

☐ Don't know [go to question 47]

40. [bidhigh] Would you be willing to support the implementation of the EU Energy Security Strategy to guarantee the reliability and the affordability of energy until 2030 if your annual electricity bill was € [20, 50, 100, 200] more expensive for the next five years?

☐ YES [go to question 48]

☐ NO [go to question 48]

☐ Don't know [go to question 48]

41. [bidlow] Would you be willing to support the implementation of the EU Energy Security Strategy to guarantee the reliability and the affordability of energy until 2030 if your annual electricity bill was €[5, 10, 20, 50] more expensive for the next five years?

☐ YES
☐ NO
☐ Don't know

What is the highest increase in your annual electricity bill for the next five years that you would be willing to pay to implement the EU Energy Security Strategy to guarantee the reliability and the affordability of energy at least until 2030?

€________

Which reasons best describe your choices to pay or not to pay for the implementation of the EU Energy Security Strategy? [Tick all that apply]

☐ The reliability and the affordability of energy are important
☐ I cannot afford to pay more for my electricity bill
☐ I am not interested in the reliability and the affordability of energy supply
☐ I don't believe that the Energy Security Strategy can be implemented
☐ I don't believe the hypothetical scenario of an increase in electricity bill
☐ Others, such as the government and industry, should pay for the Energy Security Strategy.

Section H: Options for energy security and personal preferences

We ask you to say if you agree or disagree with the following statements:

	Completely disagree					Completely agree	
I want to reduce my energy consumption	1	2	3	4	5	6	7
If I don’t support the implementation of the EU Energy Security Strategy, and then I will be restricted with the use of energy, I will later wish that I had	1	2	3	4	5	6	7
If I don’t support the implementation of the EU Energy Security Strategy, and then my family will be restricted with the use of energy, I will later feel bad for my family	1	2	3	4	5	6	7

45. **There are different ways in which the security of the supply of energy could be improved. How do you evaluate the following options?** (1 = very unacceptable to 7 = very acceptable & 1 = very negative to 7 = very positive)

Increase centralized energy production (as nuclear, coal and gas fired power plants)

Very unacceptable	1	2	3	4	5	6	7	Very acceptable
Very negative	1	2	3	4	5	6	7	Very positive

Increase decentralized, more local, energy production (e.g. private solar panels, wind turbines)

Very unacceptable	1	2	3	4	5	6	7	Very acceptable
Very negative	1	2	3	4	5	6	7	Very positive

Use less energy during peak times by adjusting your energy behaviour: You yourself decide which devices you will use during non-peak times making decisions yourself about which devices you will wait to use until there is a large supply of energy (for example the washing machine). You have control over which devices will be turned on at non-peak times.

Very unacceptable	1	2	3	4	5	6	7	Very acceptable
Very negative	1	2	3	4	5	6	7	Very positive

Use less energy during peak times by letting technologies schedule your energy use. Convenience technology turns on devices during non-peak times. For example, a grid in the house turns devices (for example your washing machine) on only when there is a large supply of energy, you don't have to do anything yourself. You do not have control over which devices will be turned on during non-peak times.

Very unacceptable	1	2	3	4	5	6	7	Very acceptable
Very negative	1	2	3	4	5	6	7	Very positive

46. **Among the following inconveniences created by interruptions in the supply of electricity, please select those more relevant to you in the following list**

☐ Non-operating security and alarm systems ☐ Suddenly remaining in the dark

☐ Interrupted telecommunications ☐ Inability to use the TV

☐ Inability to use the PC ☐ No heating

☐ Inability to recharge mobile phones ☐ Inability to recharge electric vehicles

☐ Inability to cook ☐ Spoiled food in the fridge

☐ Spoiled food in the freezer ☐ Remaining stuck in a closed room

☐ Remaining stuck in an elevator ☐ Damage to appliances

☐ Loss of data from your computer ☐ other ……………………………………….

47. **What was your total household income before taxes during the past 12 months?**

<question is empty allowed>

☐ Less than 10,000 Euros

☐ 10,000 to 29,999 Euros

☐ 30,000 to 59,999 Euros

☐ 60,000 to 99,999 Euros

☐ 100,000 to 149,999 Euros

☐ 150,000 or more Euros

The interview is now completed.

If you are interested, the aggregated survey results and analysis from this survey will be available at http://publications.jrc.ec.europa.eu/repository/ in the coming months (search for 'survey on VOLL').

We thank you for your kind participation.

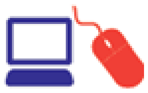
Annex B: Technical Description of the phases of the fieldwork from SSI S.A.

Kick-off call

After the project had been awarded and the questionnaire draft was ready, SSI had a kick-off call to review the project and to clarify the questionnaire, quotas and timeline details.

Questionnaire delivery and review

- Sander Ooms and Rafael de Kock (dedicated project management team) had a kick-off call with Sergio Giaccaria and Tilemahos Efthimiadis and conducted a thorough questionnaire review to ensure:
    - All skip patterns are logical and correctly point to questions in the survey
    - Question numbers and punch values are consistent, don't overlap, match with routing instructions
    - Wording, spelling, grammar is consistent for the Dutch market
    - Numeric questions have data ranges as specified



Questionnaire programming, testing and revisions

SSI expected changes and revisions to happen along the way and have developed a system to incorporate them without risking errors.

Before and during the programming of the questionnaire SSI:

- Requested and received the localized questionnaire in Dutch, Portuguese and Estonian in Word format from the European Commission.
- Requested changes via e-mail in a table and in an Excel file with question number for each change.
- SSI compiled questions/clarifications in batches for review.
- SSI controlled each version of the questionnaire and submitted a highlighted version for the European Commission's approval after each round or revision.
- SSI alerted the European Commission when changes were incorporated and tested.
- SSI checked the Dutch language questionnaire, as Sander Ooms is a native Dutch speaker. Sander Ooms shared his thoughts and gave feedback on wording and grammar. This was implemented upon approval by the European Commission.
- Multiple Dutch, Portuguese and Estonian language experts from the European Commission, checked the translated test links for quality and wording.
- SSI sent test links to the European Commission for final review and approval after SSI had done a thorough quality review.

Soft launch - Pilot

The soft launch gathered 5 %-10 % of the required completes.

Data quality check

After soft launch completion, SSI provided the interim data and a report of incidence, length and drop rate. There were no deviations from the bid specifications.

Full launch

Once the soft launch – pilot data was approved, SSI moved to the full launch. Here, quota management was important. The SSI team carefully monitored quota and adjusted sample as needed. SSI kept the European Commission team regularly updated.

Data delivery

SSI conducted data checks to remove excessive speeders and completes showing evidence of fraud or repeated inattention. SSI used multiple checks before flagging the data based on speeding and bad open answers.

SSI delivered final cleaned SPSS and Excel data files to you within hours of fieldwork completion.

Measuring Success Rates

Please note that SSI is unable to share response rates with the European Commission. Measuring response rates in a multi-source, routed environment is practically impossible – in fact it is very difficult to calculate them in any online environment. As mentioned, SSI employs a routing environment to efficiently allocate willing participants to surveys they are best suited for and are more likely to be able to complete. This reduces the self-selection bias associated with invitation-based methods and increases participant satisfaction with the market research process. There is therefore no concept of a response rate except the conversion from being asked to do a specific survey once in the router and starting that survey.

AAPOR (the American Association for Public Opinion Research) believes that the best that can be provided for a non-probability access panel is a "participation rate" since numbers of contacts at the first stage (recruitment) are unknown. Note: since we do not send survey-specific invitations, the SSI definition of participation rate is the number of starts which did not drop out of the survey. They also recognize that panel management processes (particularly how often inactive panelists are removed from the database) has an effect on participation rates. Thus any measurement of 'response' (participation) will not be an indicator of panel quality per se nor necessarily comparable to the same panel over time, nor comparable to other panels.

Interview Length

Please note that interview length per country can differ due to varying internet speeds.

Country	Median survey length
Netherlands	16:31 minutes
Portugal	19:26 minutes
Estonia	24:00 minutes

Quota control

SSI delivered a report link to the European Commission so that fieldwork progress and quota management could be monitored.

SSI had a quota on Version per country. Please see below the completes per version (A, B, C, D and E) and per country (Estonia, Netherlands and Portugal):

hlang (Single)	hVersions (Single)	Limit	Count
Estonia	Ver-A	1	209
Estonia	Ver-B	1	208
Estonia	Ver-C	1	208
Estonia	Ver-D	1	209
Estonia	Ver-E	1	209
Netherlands	Ver-A	1	207
Netherlands	Ver-B	1	208
Netherlands	Ver-C	1	208
Netherlands	Ver-D	1	208
Netherlands	Ver-E	1	207
Portugal	Ver-A	1	211
Portugal	Ver-B	1	211
Portugal	Ver-C	1	212
Portugal	Ver-D	1	212
Portugal	Ver-E	1	213

All soft launch completes (between 109 and 132 for each country) were considered as version A and WTA first. That's why those numbers are a bit higher. After the soft launch / pilot SSI S.A. added the other 4 versions and the WTA First and WTP First logic.

hlang (Single)	hRandom (Single)	hVersions (Single)	Limit	Count
Estonia	WTA - First	Ver-A	1	132
Estonia	WTP - First	Ver-A	1	77
Estonia	WTA - First	Ver-B	1	104
Estonia	WTP - First	Ver-B	1	104
Estonia	WTA - First	Ver-C	1	104
Estonia	WTP - First	Ver-C	1	104
Estonia	WTA - First	Ver-D	1	104
Estonia	WTP - First	Ver-D	1	105
Estonia	WTA - First	Ver-E	1	104
Estonia	WTP - First	Ver-E	1	105
Netherlands	WTA - First	Ver-A	1	120
Netherlands	WTP - First	Ver-A	1	87
Netherlands	WTA - First	Ver-B	1	104
Netherlands	WTP - First	Ver-B	1	104
Netherlands	WTA - First	Ver-C	1	104
Netherlands	WTP - First	Ver-C	1	104
Netherlands	WTA - First	Ver-D	1	104
Netherlands	WTP - First	Ver-D	1	104
Netherlands	WTA - First	Ver-E	1	103
Netherlands	WTP - First	Ver-E	1	104
Portugal	WTA - First	Ver-A	1	109
Portugal	WTP - First	Ver-A	1	102
Portugal	WTA - First	Ver-B	1	106
Portugal	WTP - First	Ver-B	1	105
Portugal	WTA - First	Ver-C	1	106
Portugal	WTP - First	Ver-C	1	106
Portugal	WTA - First	Ver-D	1	106
Portugal	WTP - First	Ver-D	1	106
Portugal	WTA - First	Ver-E	1	107
Portugal	WTP - First	Ver-E	1	106

Quota - Total Number of completes

hlang (Single)	Limit	Count
Estonia	9999	1043
Netherlands	9999	1038
Portugal	9999	1059

In accordance with the European Commission, the target for the oldest age group for Estonia was relaxed and completes were compensated in the 55-64 age group.

hAge (Single)	hlang (Single)	Q3 (Single)	Limit	Count	Rem.
25-34	Estonia	Male	105	76	29
35-44	Estonia	Male	105	104	1
45-54	Estonia	Male	95	96	-1
55-64	Estonia	Male	84	86	-2
65+	Estonia	Male	84	77	7
25-34	Estonia	Female	105	105	0
35-44	Estonia	Female	95	96	-1
45-54	Estonia	Female	95	95	0
55-64	Estonia	Female	175	183	-8
65+	Estonia	Female	179	125	54
25-34	Netherlands	Male	95	91	4
35-44	Netherlands	Male	105	101	4
45-54	Netherlands	Male	116	115	1
55-64	Netherlands	Male	95	91	4
65+	Netherlands	Male	116	112	4
25-34	Netherlands	Female	95	91	4
35-44	Netherlands	Female	105	101	4
45-54	Netherlands	Female	116	112	4
55-64	Netherlands	Female	95	91	4
65+	Netherlands	Female	137	133	4
25-34	Portugal	Male	95	96	-1
35-44	Portugal	Male	105	106	-1
45-54	Portugal	Male	105	106	-1
55-64	Portugal	Male	84	85	-1
65+	Portugal	Male	116	118	-2
25-34	Portugal	Female	95	96	-1
35-44	Portugal	Female	105	108	-3
45-54	Portugal	Female	105	105	0
55-64	Portugal	Female	95	97	-2
65+	Portugal	Female	158	142	16

hlang (Single)	PKLRQ45 (Single)	Limit	Count
Estonia	10	1	261
Estonia	20	1	261
Estonia	50	1	260
Estonia	100	1	261
Netherlands	10	1	260
Netherlands	20	1	260
Netherlands	50	1	259
Netherlands	100	1	259
Portugal	10	1	264
Portugal	20	1	265
Portugal	50	1	265
Portugal	100	1	265

Annex C: Econometric strategy for discrete choices analysis

The Random Utility Model

To motivate the statistical analysis of the responses to DCE questions, it is assumed that the choice between the alternatives is driven by the respondent's underlying utility. The respondent's indirect utility is broken down into two components. The first component is deterministic, and is a function of the attributes of alternatives, characteristics of the individuals, and a set of unknown parameters, while the second component is an error term. Formally, the random utility model can be described as:

$$V_{ij} = \overline{V}(\mathbf{x}_{ij}, \boldsymbol{\beta}) + \varepsilon_{ij} \quad [3]$$

where subscript *i* denotes the respondent, subscript *j* denotes the alternative, *x* is the vector of attributes that vary across alternatives (or across alternatives and individuals), and ε is an error term that captures individual and alternative-specific factors that influence utility, but are not observable to the researcher.

In many applications, it is further assumed that $\overline{V}$, the deterministic component of utility, is a linear function of the attributes of the alternatives and of the respondent's residual income, (y - C):

$$V_{ij} = \beta_0 ASC1 + \beta_{SQ} ASC3 + \mathbf{x}_{ij}\boldsymbol{\beta}_1 + (y_i - C_j)\beta_2 + \varepsilon_{ij} \quad [4]$$

where *ASC1* and *ASC3* are alternative specific constants for one alternative and the current situation (status quo), normalised to zero for the remaining alternative, β_0 is the coefficient of the first alternative, β_{SQ} is the coefficient for the status quo alternative see (Meyerhoff, 2015) for a similar use of ASCs in choice experiments studies, *y* is income, β_2 is the marginal utility of income, and *C* is the price of the commodity or the cost of the program to the respondent.

As mentioned, respondents are assumed to choose the alternative in the choice set that results in the highest utility. Because the observed outcome of each choice task is the selection of one out of *K* alternatives, the appropriate econometric model is a discrete choice model expressing the probability that alternative *k* is chosen. Formally:

$$\pi_{ik} = \Pr(V_{ik} > V_{i1}, V_{ik} > V_{i2}, ..., V_{ik} > V_{iK}) = \Pr(V_{ik} > V_{ij}) \quad \forall j \neq k \quad [5],$$

where π_{ik} signifies the probability that option *k* is chosen by individual *i.* This means that

$$\pi_{ik} = \Pr(\beta_0 ASC1 + \beta_{SQ} ASC3 + \mathbf{x}_{ik}\boldsymbol{\beta}_1 + (y_i - C_{ik})\beta_2 + \varepsilon_{ik} > \beta_0 ASC1 + \beta_{SQ} ASC3 + \mathbf{x}_{ij}\boldsymbol{\beta}_1 + (y_i - C_{ij})\beta_2 + \varepsilon_{ij}) \ \forall j \neq k \quad [6]$$

from which follows that

$$\pi_{ik} = \Pr[(\varepsilon_{ij} - \varepsilon_{ik}) < (\mathbf{x}_{ik} - \mathbf{x}_{ij})\boldsymbol{\beta}_1 - (C_{ik} - C_{ij})\beta_2) \quad \forall j \neq k \quad [7]$$

Equation [5] shows the probability of selecting an alternative no longer contains terms in [4] that are constant across alternatives, such as the intercept and income. It also shows that the probability of selecting *k* depends on the differences in the levels of the attributes across alternatives, and that the negative of the marginal utility of income is the coefficient on the difference in cost or price across alternatives (Longo, Markandya, & Petrucci, The internalization of externalities in the production of electricity: willingness to pay for the atributes of a policy for renewable energy, 2008).

Multinomial Logit Model

If the error terms ε are independent and identically distributed and follow a standard type I extreme value distribution, one can derive a closed-form expression for the probability that respondent i picks alternative k out of K alternatives.

Since the CDF of the standard type I extreme value distribution is $F(\varepsilon)=\exp(-e^{-\varepsilon})$, and its pdf is $f(\varepsilon_i)=\exp(-\varepsilon_i-e^{-\varepsilon_i})$, choosing alternative k means that $\varepsilon_k+V_k>\varepsilon_j+V_j$ for all j≠k, which can be written as $\varepsilon_j<\varepsilon_k+V_k-V_j$. The probability of choosing *k* is, therefore,

$$\pi_{ik}=\Pr(\varepsilon_{ij}<\varepsilon_{ik}+V_{ik}-V_{ij}) \text{ for all j≠k}$$

$$=\int_{-\infty}^{+\infty}\prod_{j\neq k}F(\varepsilon_{ik}+V_{ik}-V_{ij})\cdot f(\varepsilon_{ik})d\varepsilon_{ik} \qquad [8]$$

Expression [8] follows from the assumption of independence, and the fact that ε_k is an error term and not observed, so that it is must be integrated out of $F(\varepsilon_{ik}+V_{ik}-V_{ij})$. The product within expression [8] can be re-written as

$$\prod_{j\neq k}F(\varepsilon_{ik}+V_{ik}-V_{ij})\cdot f(\varepsilon_{ik}) = \prod_{j\neq k}\exp(-e^{-\varepsilon_{ik}-V_{ik}+V_{ij}})\exp(-\varepsilon_{ik}-e^{-\varepsilon_{ik}}) \qquad [9]$$

$$=\exp\left[-\varepsilon_{ik}-e^{-\varepsilon_{ik}}\left(1+\sum_{j\neq k}\frac{e^{V_{ij}}}{e^{V_{ik}}}\right)\right].$$

Given that

$$\lambda_{ik}=\log\left(1+\sum_{j\neq k}\frac{e^{V_{ij}}}{e^{V_{ik}}}\right)=\log\left(\sum_{j=1}^{K}\frac{e^{V_{ij}}}{e^{V_{ik}}}\right) \qquad [10],$$

we can rewrite [8] as

$$\int_{-\infty}^{+\infty}\exp(-\varepsilon_{ik}-e^{-(\varepsilon_{ik}-\lambda_{ik})})d\varepsilon_{ik} = \exp(-\lambda_{ik})\int_{-\infty}^{+\infty}\exp(-\varepsilon_{kk}^{*}-e^{-\varepsilon_{kk}^{*}})d\varepsilon_{ik}^{*}, \qquad [11]$$

where $\varepsilon_{ik}^{*}=\varepsilon_{ik}-\lambda_{ik}$. The integrand in expression (9) is the pdf of the extreme value distribution and is equal to 1. Equation (9) thus simplifies to $\exp(-\lambda_{ik})$, which by (8) is in turn equal to $\exp(V_{ik})/\sum_{j=1}^{K}\exp(V_{ij})$.

Recalling (2), the probability that respondent i picks alternative k out of K alternatives is

$$\pi_{ik}=\frac{\exp(\mathbf{w}_{ik}\boldsymbol{\beta})}{\sum_{j=1}^{K}\exp(\mathbf{w}_{ij}\boldsymbol{\beta})} \qquad [12]$$

where $\mathbf{w}_{ij}=\begin{bmatrix}\mathbf{x}_{ij}\\ C_{ij}\end{bmatrix}$ is the vector of all attributes of alternative j, including cost, and $\boldsymbol{\beta}$ is equal to $\begin{bmatrix}\boldsymbol{\beta}_1\\ -\beta_2\end{bmatrix}$.(7)

(7) The intercept in equation (2) is not identified and is therefore normalized to zero.

Equation (10) is the contribution to the likelihood in a multinomial logit model (MNL). The full log likelihood function of the MNL is([8])

$$\log L = \sum_{i=1}^{n} \sum_{k=1}^{K} y_{ik} \cdot \log \pi_{ik} \qquad [13]$$

where y_{ik} is a binary indicator that takes on a value of 1 if the respondent selects alternative *k,* and 0 otherwise. The coefficients are estimated using the method of Maximum Likelihood (MLE).

We can further examine the expression for π_{ik} in equation (10) to show that π_{ik} depends on the differences in the level of the attributes between alternatives. To see that this the case, we begin by re-writing (10) as

$$\pi_{ik} = \frac{\exp(\mathbf{w}_{ik}\boldsymbol{\beta})}{\sum_{j=1}^{K}\exp(\mathbf{w}_{ij}\boldsymbol{\beta})} = \left[\frac{\exp(\mathbf{w}_{ik}\boldsymbol{\beta})}{\exp(\mathbf{w}_{i1}\boldsymbol{\beta}) + \ldots + \exp(\mathbf{w}_{ik}\boldsymbol{\beta}) + \ldots + \exp(\mathbf{w}_{iK}\boldsymbol{\beta})}\right] \qquad [14]$$

which is equal to

$$= \left[\frac{\exp(\mathbf{w}_{i1}\boldsymbol{\beta}) + \ldots + \exp(\mathbf{w}_{ik}\boldsymbol{\beta}) + \ldots + \exp(\mathbf{w}_{iK}\boldsymbol{\beta})}{\exp(\mathbf{w}_{ik}\boldsymbol{\beta})}\right]^{-1} \qquad [15]$$

and thus to

$$= \left\{\exp\left[(\mathbf{w}_{i1} - \mathbf{w}_{ik})\boldsymbol{\beta}\right] + \ldots + 1 + \ldots + \exp\left[(\mathbf{w}_{ik} - \mathbf{w}_{iK})\boldsymbol{\beta}\right]\right\}^{-1} \qquad [16]$$

For large samples and assuming that the model is correctly specified, the maximum likelihood estimates $\hat{\beta}$ are normally distributed around the true vector of parameters β, and the asymptotic variance-covariance matrix, Ω, is the inverse of the Fisher information matrix. The information matrix is defined as

$$I(\beta) = \sum_{i=1}^{n} \sum_{k=1}^{K} \pi_{ik} (\mathbf{w}_{ik} - \overline{\mathbf{w}}_i)(\mathbf{w}_{ik} - \overline{\mathbf{w}}_i)' \qquad [17]$$

where $$\overline{\mathbf{w}}_i = \sum_{k=1}^{K} \pi_{ik} \mathbf{w}_{ik} \qquad [18]$$

([8]) Note that 'log' is the natural logarithm.

Marginal prices and WTP

Once the model [13] is estimated, the rate of trade-off between any two attributes is the ratio of their respective β coefficients. The marginal value of attribute l is computed as the negative of the coefficient on that attribute, divided by the coefficient on the price or cost variable:

$$MP_l = -\frac{\hat{\beta}_l}{\hat{\beta}_2} \quad [19].$$

The WTP for a commodity is computed as:

$$WTP_i = -\frac{\mathbf{x}_i \hat{\boldsymbol{\beta}}_1}{\hat{\beta}_2} \quad [20],$$

where *x* is the vector of attributes describing the commodity assigned to individual *i*. It should be kept in mind that a proper WTP can only be computed if the choice set for at least some of the choice sets faced by the individuals contains the "status quo" (in which no commodity is acquired and the cost is zero). Expression (17) is obtained by equating the indirect utility associated with commodity $\mathbf{x}_i$ and residual income $(y-C)$ with the indirect utility associated to the status quo (no commodity) and the original level of income *y* and solving for *C*.

When reporting the estimates of the marginal prices of the attributes and the WTP, it is important to report the standard errors around these estimates. As shown in (16) and (17), marginal prices and WTP are the ratios of variables that in large samples are jointly normally distributed. This means that standard errors around them must be computed using the delta method, or, alternatively, simulation-based procedures.

To apply the delta method to get the standard error around the estimate of the marginal price of attribute l, let $g = -\frac{\beta_l}{\beta_2}$. The variance around marginal price [19] is thus:

$$Var(MP_l) = \frac{\partial g}{\partial \boldsymbol{\beta}'} \Omega \frac{\partial g}{\partial \boldsymbol{\beta}} \quad [20],$$

where $\frac{\partial g}{\partial \boldsymbol{\beta}'}$ is a vector of zeros, except for the l-th element, which is ($-1/\beta_2$), and the last element, which is β_l / β_2^2. In practice, all of the parameters in the expression for g and in [21] will be replaced with their estimates. The standard error is the square root of [21]. When we use the delta method to produce the variance around [20], we still use expression [20], but $\frac{\partial g}{\partial \boldsymbol{\beta}'}$ is in this case equal to $\left[-\mathbf{x}_i / \beta_2 \quad \mathbf{x}_i / \beta_2^2\right]$.

Heterogeneity

The MNL described by equations (10)-(11) is easily amended to allow for heterogeneity among the respondents, as different respondents may have different tastes for an electricity service bundle. Specifically, one can form interaction terms between individual characteristics, such as age, gender, education etc., and the current situation, or all or some of the attributes, and enter these interactions in the indirect utility function. For example, if it was believed that the marginal utility of the attributes of, say, a program that improves the provision of electricity services varies with the location where a customer lives, one might specify utility as:

$$V_{ij} = \beta_0 ASC1 + \beta_{SQ} ASC3 + \mathbf{x}_{ij}\boldsymbol{\beta}_1 + (y_i - C_j)\beta_2 + (ASC3 \times R_i)\boldsymbol{\beta}_3 + \varepsilon_{ij} \quad [21],$$

where R is a dummy denoting, for example, that the individual lives in a rural area. The interaction term ($ASC3 \times R_i$) varies across respondents, and one retains the ability to estimate the coefficients $\boldsymbol{\beta}_3$.

However, it is possible that some of the heterogeneity in respondents' preferences may not be captured by respondents' characteristics, and remain unobserved by the researcher. The limitations of the MNL model in accommodating preference heterogeneity have given rise to a suite of models that fit under the mixed logit models umbrella. Such models have a number of attractions and can provide a flexible, theoretical and computationally practical econometric method for any discrete choice model derived from random utility maximisation. The central feature of mixed logit models is their ability to accommodate random taste variation which is generally shown to significantly improve model fit, as well as provide greater insights into choice behaviour and welfare estimation.

In mixed logit models the values of the coefficient estimates are allowed to vary across individual respondents. There is a variety of different behavioural specifications for the random variation. Choosing the appropriate specification depends on the empirical data and should be considered on a case-by-case basis. The behavioural specifications are typically based on either a continuous or discrete mixing distribution of the random taste variation (or some combination of the two).

Under continuous mixing distributions, such model specifications are commonly referred to as Random Parameters Logit (RPL) models. These models mainly provide the analyst with information on the mean, potentially the mode, and the spread, while more flexible distributions also give additional shape information. Retrieving such information provides a rich insight into the range of taste intensities held by the respondents. Not surprisingly, RPL models have become an established and frequently used specification. In the environmental economics literature it has become increasingly common and often expected practice to use RPL models to handle preference heterogeneity.

A key element with the specification of random taste variation in RPL models is the assumption regarding the distribution of each of the random parameters. The distribution of random parameters can take a number of predefined functional forms. While this gives the analyst some control and flexibility, the random parameters are not observed and there is typically little a priori information about the shape of its distribution except possibly a sign constraint. Consequently, the chosen distribution is essentially an arbitrary approximation requiring some possibly strong or unwarranted distributional assumptions about individual heterogeneity.

One of the drawbacks in using RPL models is that they are not very suitable in accommodating for observed heterogeneity. Often, when trying to investigate both observed and unobserved heterogeneity the analyst finds spurious results, with many coefficient estimates not statistically significant because the coefficient estimates capturing observed and unobserved heterogeneity tend to ‘compete’ with each other to investigate consumers’ preferences.

Therefore, it is advisable to estimate MNL models augmented with socio-economic variables to investigate observed heterogeneity, to assess differences in WTP across different types of respondents, and then to use RPL models to select the model that fits the data better. The model with the best fit should be used for policy analysis if one is interested in the preferences of the whole sample.

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