Guidelines of Good Practice on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances

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INFORMATION PAGE

Abstract

This document (C10-EQS-41-03) is a CEER document on Guidelines of Good Practice on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances.

These recommendations apply for cost-estimation studies on customer and society costs due to electricity interruptions and voltage disturbances. They include explanations of all steps during a study, including a checklist, and give recommendations on the choices to be taken within all steps, though some choices will depend upon country-specific characteristics.

Target Audience

National Regulatory Authorities, Member States, transmission and distribution system operators, consumer representative groups, academics, researchers, consultants and other interested parties.

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Related Documents

CEER/ERGEG documents

[1] "Third Benchmarking Report on Quality of Electricity Supply 2005", CEER, December 2005, Ref. C05-QOS-01-03, http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_ERGEG_PAPERS/Electricity/2005/CEER_3RDBR-QOES_2005-12-06.PDF

[2] "4th Benchmarking Report on Quality of Electricity Supply", CEER, December 2008, Ref. C08-EQS-24-04, http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_ERGEG_PAPERS/Electricity/2009/C08-EQS-24-04_4th%20Benchmarking%20Report%20EQS_10-Dec-2008_re.pdf

External documents

[3] "Study on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances", SINTEF Energy Research (www.sintef.no), October 2010, Ref. TR F6978, available through http://www.energy-regulators.eu.

[4] "Customer Costs Related to Interruptions and Voltage Problems: Methodology and Results", Kjølle, Gerd H.; Samdal, Knut; Singh, Balbir; Kvitastein, Olav A, 2008, IEEE

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[5] ”Incorporating short interruptions and time dependency of interruption costs in continuity of supply regulation”, Kjølle, Gerd H.; Samdal, Knut; Brekke, Karstein, June 2009, Proc. 20th International conference and exhibition on electricity distribution, CIRED, Prague, Paper 494, http://www.cired.be.

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[9] "Toward Voltage-Quality Regulation in Italy", M. Delfanti, E. Fumagalli, P. Garrone, L. Grilli, L. Lo Schiavo, April 2010, IEEE Transactions on Power Delivery, Vol. 25, No. 2, pp. 1124-1132.

[10] “Pan-European Power Quality Survey. A study of the impact of power quality on electrical energy critical industrial sectors.”, R. Targosz, J. Manson, October 2007, 9th International Conference, Electrical Power Quality and Utilisation, Barcelona, http://www.leonardo-energy.org/drupal/files/EPQU/2007conference/p329.pdf?download

[11] “Pan European LPQI Power Quality Survey”, R. Targosz, J. Manson, May 2007, Proc. 19th International conference and exhibition on electricity distribution, CIRED, Vienna, Paper 0263, http://www.leonardo-energy.org/drupal/files/2007/CIR07-Final_paper_0263.pdf?download

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EXECUTIVE SUMMARY

The Council of European Energy Regulators (CEER) has prepared Guidelines of Good Practice (GGP) on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances. In order to help prepare these GGP, a consultancy study on the issue was commissioned by CEER. SINTEF Energy Research prepared a consultancy report[1] on "Estimation of Costs due to Electricity Interruptions and Voltage Disturbances" which served as a basis for this CEER document.

There is a growing interest Europe-wide in cost-estimation studies to reveal costs due to electricity quality deviations. Activity in this area is witnessing differing levels of development across European countries and CEER deemed it useful to try to set out European guidelines in the domain of nationwide studies on estimation of costs due to electricity interruptions and voltage disturbances. This work is also based on the practical experience available in some countries. CEER's main objectives are:

1. to provide a set of recommendations for national energy regulatory authorities (NRAs) and other interested parties on how to design and develop nationwide cost-estimation studies; and
2. to highlight possible problems (already experienced by some countries), in order to improve the effectiveness of future studies and the quality and comparability of their results. This report also highlights three national experiences of these types of studies, which can be useful for NRAs that want to set up studies in future.

The typical structure for a cost-estimation study on electricity interruptions and voltage disturbances can be divided into a "survey-based approach" and a "case-based approach". "Survey-based approaches" typically include the design of a questionnaire which is sent out to a large representative sample. On the other hand, the "case-based approaches" focus on a few single cases in order to identify consequences of interruptions or voltage disturbances for these typical cases. Both approaches could be used for all customer groups; however, CEER mainly recommends that either a "survey" or a "case" based approach is used to elicit the costs for the different customer groups.

These CEER GGP for studies on costs due to **electricity interruptions and voltage disturbances** include recommendations on:

- Definition of objectives;
- Choice of consultants;
- Specification of customer groups;
- Choice of cost-estimation method;
- Choice of normalisation factor and clarification of data needs;
- Check for available data;
- Choice of conduction method (means by which the survey/case analysis is performed);

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[1] "Study on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances", SINTEF Energy Research (www.sintef.no), November 2010, Ref. TR F6978, available through http://www.energy-regulators.eu.

- Design of questionnaires and scenarios;
- Sample selection;
- Test of questionnaires;
- Survey conduction: how to conduct the survey/case analysis;
- Selection of cases;
- Analysis of cases; and
- Cost analysis.

In addition, as regards costs due to **voltage disturbances,** the CEER recommendations cover a few additional aspects, specifically for case-based VQ studies:

- Deployment of measurement instruments;
- Logging of events; and
- Analysis of log forms and measurement data.

CEER believes that one of the most important tasks for NRAs, before conducting a nationwide cost estimation study, is to choose the best consultants to assist or to carry out the work based on the NRA's objective[2]. Consultants are often used for parts or even for the complete cost-estimation study. Consultants may be used for the choice of cost-estimation method; design of questionnaires, conduction of the study; selection and analysis of cases, deployment of measurement instruments, analysis of log forms and measurement data and cost analysis, depending on whether a survey-based approach or a case-based approach is chosen and whether the study covers electricity interruptions and/or voltage disturbances.

Different tasks require different expertise; hence the consultants' experience and competence need to be checked in detail before they are contracted for any part of the work. CEER believes it is imperative that the consultants have proper knowledge and experience of survey methodology and conduction, economics, mathematics, statistics (complex statistical analysis and regression analysis), the electrical power system and the technical details of interruptions and voltage disturbances, depending on which parts the consultant will be involved in. When performing a cost-estimation study on voltage disturbances, practical experience with voltage quality including real measurements will be an advantage. The respective NRA should in any case be involved in the consultants' work, ensuring regulatory supervision at each stage of the process.

[2] If different stakeholders contribute financially to the cost-estimation study; a joint objective for all stakeholders should be developed.

CEER has drawn the following **conclusions** from its work on this issue:

C-1: Results from cost-estimation studies on customer costs due to electricity interruptions are of key importance in order to be able to set proper incentives[3] *for continuity of supply.*

C-2: Results from cost-estimation studies on customer costs due to voltage disturbances are important input[4] *on the consequences of various voltage disturbances when deciding where to focus regulation.*

C-3: Society costs should be considered in addition to customer costs when doing a cost-estimation study, as these can differ significantly.

C-4: National Regulatory Authorities should perform nationwide cost-estimation studies regarding electricity interruptions and voltage disturbances.

C-5: A pre-study should be performed in advance of a main study in order to define the objectives and to clarify country-specific characteristics, budget and consultancy needs, possible funding partners, timeline and possibilities in general for the main study.

C-6: These GGP – including the SINTEF consultancy report – should be used as a reference when performing a nationwide cost-estimation study, always taking into account country-specific issues and needs.

C-7: Results and experience from cost-estimation studies shall be disseminated among interested stakeholders.

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[3] Including load shedding, contingency planning, preventive maintenance, softened N-1 criterion, ordinary (income) incentive based schemes, payment schemes.

[4] A cost-estimation study is not a prerequisite for introducing regulatory requirements on voltage quality. In particular requirements for continuous phenomena can be introduced without a cost-estimation study performed in advance, see also ERGEG Public Consultation and Conclusions papers on "Towards Voltage Quality Regulation in Europe"; Ref.: E06-EQS-09-03 and E07-EQS-15-03.

1 Introduction

1.1 Quality of electricity supply

Quality of electricity supply can be divided into three main elements: the availability of electricity (continuity of supply), its technical properties (voltage quality) and the speed and accuracy with which customer requests are handled (commercial quality). The quality of electricity supply has implications on the functioning of the European industry, and hence, for its part, the European electricity infrastructure influences the competitiveness of the European industry compared to other industrial regions of the world.

Continuity of supply represents the availability of electricity. When electricity supply is temporarily not available, this is referred to as an “interruption of supply” (or an “interruption”). The fewer the instances of interruptions and the shorter these interruptions are, the better is the supply from the viewpoint of the customer. The design and operation of the power system should be such that the number and duration of interruptions are acceptable to most customers, without incurring unacceptably high costs. A distinction is often made between the types of interruptions, based on their duration. In most European countries, an interruption is referred to as a “short interruption” if it lasts three minutes or less. A “long interruption” is an interruption that lasts more than three minutes. The reason for this distinction has to do with the way in which continuity data has traditionally been collected. The effect of interruptions on customers varies a lot depending on the type of customer, time of occurrence of the interruption, interruption duration, frequency of occurrence, etc. Traditionally, for many customers, the impact of a 1-minute interruption is much less than the impact of a 1-hour interruption. However, due to a number of developments, in particular within the processing industry, but also modernising of the agriculture sector, increased use of power electronics and electronic equipment, etc; the sensitivity of electrical equipment and appliances with respect to interruptions and their durations has changed over the years. The aim should be to have a balance between costs and continuity of supply benefiting society the most.

Voltage quality represents the usefulness of electricity for end-users when there are no interruptions. When the voltage quality is very poor, several problems may arise in the use of electrical appliances and electrical processes: e.g. malfunctioning, breakdown, trips, damage, reduced efficiency, flickering lights and even explosion and fire. A voltage disturbance, such as for instance a voltage dip, may have a major impact on the continuous processes within the industry, especially within certain parts of the processing industry like the paper industry or steel manufacturing. In simple terms, voltage quality can be described by deviations from nominal values for voltage frequency and voltage magnitude and by distortions of the voltage wave shape. These can be further divided into several more parameters or voltage disturbances.

1.2 Nationwide cost-estimation studies – motive

Finding a compromise between “reliability” and “costs” has been a subject of discussion for several decades now and will likely continue for years to come. Cost-estimation studies are an important tool to be able to estimate an optimal level of continuity of supply. The “optimal continuity of supply” can be different for different regions (urban versus rural) and for different types of customers (industrial versus domestic) and will certainly evolve with time as end-user equipment, customer requirements and investment costs change.

Over the past 10 to 15 years, several CEER members have implemented financial incentives in their regulation in order to optimise the level of continuity of supply seen from society as a whole [1][5]. As a basis for implementing these kinds of incentives, some European countries have conducted nationwide cost-estimation studies to reveal customers' interruption costs.

In order to find the optimal level of continuity of supply from society's point of view, it is imperative to balance the various cost-elements towards each other, i.e. the costs associated with reducing the scope of interruptions must be compared to the possible reduction in the customer's costs resulting from the same actions. **In order for NRAs to be able to implement reliable financial incentives[6] regarding continuity of supply, it is of great importance that sufficient knowledge about customers' real costs and their willingness to pay and willingness to accept is available in order to introduce or to improve such regulations.** The impact on society's costs is not the same as the impact on customers' costs and the difference is also important to consider due to the goal of many national acts and regulations.

Only some CEER members have established national minimum requirements and regulations on voltage disturbances, c.f. 4th CEER Benchmarking Report on Quality of Electricity Supply [2]. This is probably due to various legal and real competences within this field within the various NRAs. However, as from 3 March 2011, following the deadline to implement the 3rd Package[7], all European NRAs will have the legal power to introduce voltage quality requirements. Some European countries have carried out cost-estimation studies to reveal customers' costs due to voltage disturbances, although on a limited basis and only including a few parameters. In most cases, this has been investigated together with a cost-estimation study on electricity interruptions. Although results from a European cost-estimation study exist [10], [11], **cost elements due to voltage disturbances at national level are still unknown or uncertain in many European countries. Hence, it is useful for NRAs to gain new knowledge on customers' costs related to poor voltage quality.**

[5] While [1] provides a European overview as of 2005, an updated and global overview of former cost surveys and methods applied regarding costs due to interruptions and voltage disturbances is given in [3].

[6] Incentive-based regulation, penalty schemes, payment schemes, contracts, softened N-1 criterion, basis for concession applications, justification of investments, priorities for load shedding, contingency planning, preventive maintenance, etc.

[7] The 3rd legislative Package proposals for the European Internal Market in Energy were finally adopted on 13 July 2009 and include 5 legislative acts, which can be viewed at: http://eurlex.europa.eu/JOHtml.do?uri=OJ:L:2009:211:SOM:EN:HTML

1.3 The objective of these recommendations

There is a growing interest Europe-wide in cost-estimation studies due to quality deviations. Activity in this area is witnessing differing levels of development across European countries and CEER deemed it useful to try to set out European guidelines in the domain of studies on costs due to electricity interruptions and voltage disturbances, also based on the current experience available in some countries. CEER's main objective is to provide a set of recommendations on how to design and develop nationwide cost-estimation studies; and to highlight possible problems (already experienced by some countries) in order to finally improve the effectiveness of future studies and the quality and comparability of their results. These recommendations aim at providing improved methodologies for studies on customer and society costs due to interruptions and voltage disturbances in the supply of electricity as well as possible questionnaires and checklists for use in such studies.

The NRAs' interest in the need for a harmonised framework and methodology for cost-estimation studies has in the past years been focused around costs due to electricity interruptions and voltage disturbances. The methodological basis for customer satisfaction and cost analysis for poor commercial quality can be more similar to experiences from other industrial and service sectors. Indeed, a recent study examined electricity retail markets in Europe, including customer satisfaction[8]. A number of consulting firms and market research companies exist in Europe that can support NRAs in performing such studies. On the other hand, CEER believes that only a few experienced consulting organisations exist in European countries with knowledge of study methodologies on costs due to electricity interruptions and voltage disturbances (maybe not even in all countries interested in performing a nationwide cost-estimation study). Existing instruments might be adapted and used for customer satisfaction related to commercial quality. Hence, the objective of CEER's GGP is focused on continuity of supply and voltage quality, and does not include costs or dissatisfaction due to poor commercial quality.

This CEER report contains 4 chapters; Chapter 1 provides an introduction to the theme including the objective of the report; Chapter 2 provides descriptions of and recommendations on choices to be taken within the most important steps during a cost-estimation study regarding electricity interruptions and voltage disturbances, while more complete information on all steps for a cost-estimation study is included in [3]. Chapter 3 includes examples from three countries where cost-estimation studies have been performed and where the results have already been used as basis for regulatory interventions. Chapter 4 sets out CEER's conclusions from its work on this issue.

[8] ECME Consortium, "The functioning of retail electricity markets for consumers in the European Union", November 2010. Link: http://ec.europa.eu/consumers/strategy/facts_en.htm

1.4 The consultancy report

CEER commissioned a consultancy study to support the preparation of these recommendations. The consultancy report was performed by SINTEF Energy Research (www.sintef.no) between mid-June and end–October 2010. The report [3] is available via www.energy-regulators.eu. The scope of the consultancy study has been to develop guidance for how to carry out nationwide estimations of costs due to electricity interruptions and voltage disturbances in European countries. The detailed description of the scope is included in Annex 3 for information. A steering committee of CEER experts followed the technical and administrative project management. Halfway through the project, an internal CEER workshop was organised to discuss interim results, and what elements to focus on when finalising the consultancy study.

The SINTEF consultancy report is divided into two parts: part A presenting the guidance and part B describing state of the art for methodologies for customer cost studies on electricity interruptions and voltage disturbances. Part B forms the theoretical background and reasoning for the recommended guidance. Part A can be read independently of Part B, if one is not interested in the scientific reasoning of why the various approaches have been proposed.

Part A of the report summarises the proposed approaches for cost studies including, *inter alia,* specifications of customer groups, choice of cost-estimation and conduction method (i.e. the means by which the survey or case analysis is carried out), design of questionnaires and scenarios, sample selection, choice of normalisation factors and estimation of cost data. Part A gives a short and practical description of how to execute a complete cost-estimation study, structured in the sequence of a typical study. Flowcharts describing the different steps and checklists are included. The SINTEF consultancy report also gives examples of questionnaires and offers some consideration of country-specific characteristics that need special attention at national level before implementing a nationwide cost study.

Part B serves as the scientific basis for the approaches proposed in Part A and gives an overview of state of the art regarding methodologies for revealing costs through customer studies based on an extensive literature research as well as the experience of the authors of the report. Methods and approaches are presented with their advantages and disadvantages. It is described how to design a questionnaire and how to conduct a cost-estimation study including customer characteristics as well as interruptions and voltage disturbance scenarios. This part of the consultancy report deals also with the estimation of usable cost parameters from the cost-estimation results.

2 Recommendations on cost-estimation studies

2.1 Cost-terms

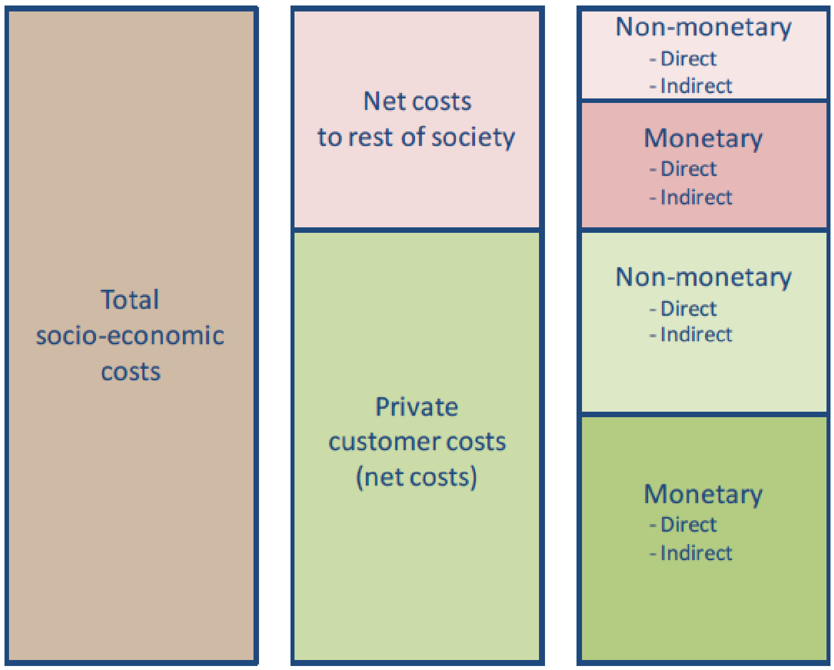

Figure 1 - Total socio-economic costs of electricity interruptions and voltage disturbances, [3]

In Figure 1, a principal overview is provided of the different cost-elements included in the total costs for society as a whole when electricity interruptions or voltage disturbances occur. Different methodologies exist to best reveal the different cost-elements. All cost-elements are well described in [3]; below we briefly describe the "net costs to the rest of society" because this might be less known to the reader. The term "rest of society" includes consequences for other people or parties than the electricity customer, but who are affected due to their relation to the customer or the customer's public or commercial services. This cost category includes monetary and non-monetary costs. One example is clients of a production facility who do not receive the intended delivery on time, which may cause spill-over effects where clients in turn lose production and are not able to serve their clients on time. Another example is the costs and inconvenience of passengers if an electricity interruption disrupts train traffic. Spill-over costs are not necessarily negative; other companies may benefit from an interruption that affects a competitor (e.g. if they can increase their sales and production).

2.2 Choice of consultants

CEER believes that one of the most important tasks for NRAs, before conducting a cost-estimation study, is to choose the best consultants to assist or to carry out the work based on the NRA's objective[9]. Consultants are often used for parts or even for the complete cost-estimation study. Consultants may be used for the choice of cost-estimation method, design of questionnaires, conduction of the study (i.e. practical implementation of the survey or case analysis), selection and analysis of cases, deployment of measurement instruments, analysis of log forms and measurement data and cost analysis, depending on whether a survey-based approach or a case-based approach is chosen and whether the study covers electricity interruptions and/or voltage disturbances. The design of the questionnaire can also comprise the choice of the customer grouping and of the conduction method. Additional tasks for the conduction of the study can be selection of the conduction method and of the sample. The consultants could even decide on the normalisation factor – but in close contact with the NRA – if the consultants are responsible for the cost analysis.

Different steps during a cost-estimation study require different expertise; hence the consultants' experience and competence needs to be checked in detail before being contracted for any of the different steps. CEER believes it is imperative that the consultants have proper knowledge and experience within survey methodology and conduction, economics, mathematics, statistics (complex statistical analysis and regression analysis), the electrical power system, the customers' systems that are influenced and the technical details of electricity interruptions and voltage disturbances, depending on which parts the consultants will be involved in. When doing a cost-estimation study on voltage disturbances, practical experiences with voltage quality including real measurements will be an advantage. The consultants should be qualified to perform power quality measurements, otherwise such services must be hired from a third party. NRAs should carefully check the different competences and experience of the consultants before they are used for any of the above-mentioned steps.

Recent experience in several countries shows that in order to achieve high quality results of nationwide cost-estimation studies, NRAs really need to follow-up the consultants very closely in all steps of the process. The respective NRA should be involved in the consultant's work, ensuring regulatory supervision at each stage as described in the flowcharts presented later in sections 2.3.1 and 2.4.1; thus simply awarding a consultant will not (automatically) lead to satisfactory results from the study.

Regarding the consultancy project supporting the development of these GGP, the consultant was expected, in particular to understand the different needs of NRAs interested in carrying out cost-estimation studies in the future; to efficiently manage the contributions and comments of experienced NRAs; to explore the wide range of methodological approaches proposed by literature globally and as applied in practical studies; and to assess the real-life complexities of carrying out and evaluating results of studies, etc. Similar knowledge and experience as described above was expected.

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[9] If different stakeholders financially contribute to a cost-estimation study; a joint objective for all stakeholders should be developed.

2.3 Recommendations for estimation of electricity interruption costs

2.3.1 Cost-estimation approaches – flowchart and checklist

This section is based on Part A of the SINTEF consultancy report regarding electricity interruptions. However, here we emphasise on those steps in a cost estimation study which are of most relevance for or require involvement of NRAs when deciding to undertake a nationwide cost-estimation study, without providing an exhaustive description. The choice of steps to be described takes into account that consultants will be involved (as described in section 2.2). All steps are described in detail in [3]. Still, recommendations provided by CEER and the consultant should be adjusted for country-specific characteristics. CEER further recommends that a pre-study should be performed in advance of a main study in order to define the objectives for the main study and to clarify country-specific characteristics, budget and consultancy needs, possible funding partners, timeline and possibilities in general for the main study.

A commonly used categorisation of types of valuation methods are “stated preference methods” (survey methods) and “revealed preference methods” (market-based methods). Stated preference methods are based on asking individuals to elicit their intended future behaviour in constructed markets.[10] Revealed preference methods base the cost estimates on the observation of real choices in the market by the customer.[11] Both methods are based on economic theory and the assumption that people are utility-maximising.

Another dimension is direct versus indirect methods. Direct methods focus explicitly on costs, either through surveys or by studying markets. Indirect methods uncover preferences and priorities (again through surveys or by studying markets) without focusing explicitly on the cost of electricity interruptions or voltage disturbances. For the latter, the cost must be estimated in a separate operation through the use of econometric models.

The typical sequence for conducting a cost-estimation study is presented in the flowchart given in Figure 2. The flowchart is divided into a survey-based approach and a case-based approach. Survey-based approaches typically include the design of a questionnaire which is sent out to a large representative sample. On the other hand, the case-based approach focuses on a few single cases to identify consequences of interruptions for these typical cases. Both approaches could be used for all customer groups. CEER recommends using either a survey-based or a case-based approach for each customer group (further background can be found in [3]). In the following, some of the important steps of these approaches will be described. A checklist for each step and for each approach is described in Table 1.

[10] This is the most common approach to estimate interruption costs [3].

[11] Examples of choices are investments in back-up generation (UPS), other mitigation approaches, insurance premiums for utility service interruption, etc.

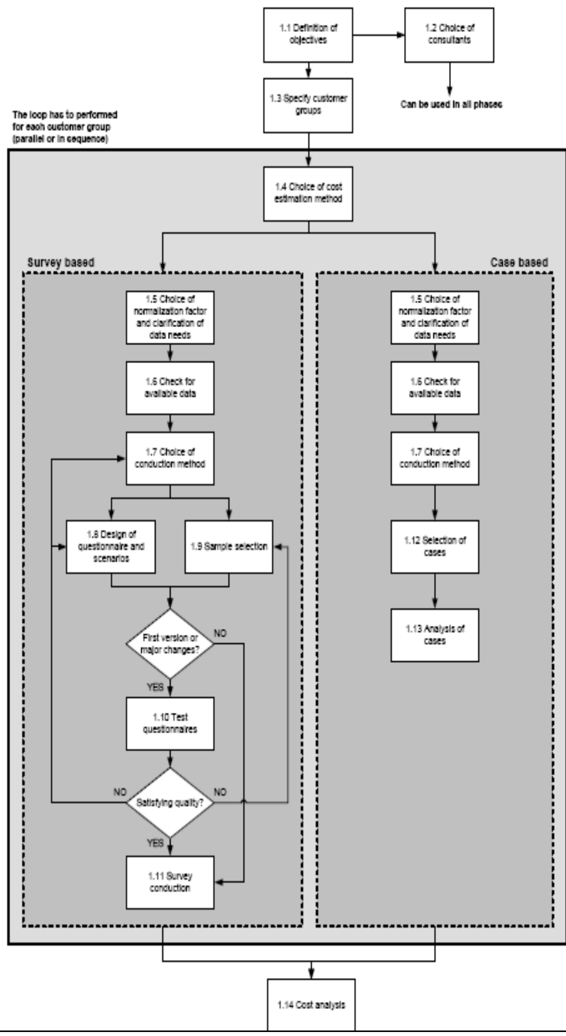

Figure 2 - Flowchart cost-estimation study of interruptions

Step	Activities
Definition of objectives	Are the objectives of the study clearly defined?
Choice of consultants	Is it clearly defined in which project phases consultants should be used?
	Do the consultants have the right competences and resources?
Specification of customer groups	Are all electricity customers of interest and eventually their supply chain and customers covered?
Choice of cost estimation method	Are competences and resources available to implement the chosen survey and conduction method?
	Are competences available to analyze the data collected with the chosen method?
Choice of normalization factor and clarification of data needs	Are data available for the normalization factor or can they be collected from other public sources?
	Are data needs for covering the most important customer characteristics identified?
	Are data needs for developing a cost function or a regression analysis depending on several attributes identified?
Check for available data	Are available data sources checked?
	Are data available for the electricity consumption for each customer?
	Are data available for the contribution to national economy by each customer group and possible sub-samples?
Choice of conduction method	Can the expected response rates be achieved with the chosen conduction method?
Design of questionnaire and scenarios	The questionnaire covers the data needs, which data are not available from other sources?
	Construction of scenarios. Do the scenarios cover enough different attributes to estimate a cost function or to perform regression analysis (in case of conjoint analysis is chosen)?
	No questions included for data which can be obtained from other available data sources?
Sample selection	Is the sample size large enough to ensure statistically significant results?
Test of questionnaires	Were respondents able to give reliable cost estimates?
	Are the achieved response rates in the same order as used for the calculation of the sample size?
Survey conduction	Are resources available to conduct the survey in the envisaged time frame?
Selection of cases	Are the selected cases typical for a larger group?
	Is the whole spectrum of customers covered?
Analysis of cases	Are the hypothetical scenarios chosen for analysis in the cases consistent with some of the scenarios in the survey based approach?
	Is it possible to do a statement on the costs of interruptions for that case after the analysis?
Cost analysis	Are competences and resources available to perform the quality assurance of data, normalization and estimation of cost data?

Table 1: Checklist for cost-estimation study of interruptions

2.3.2 Definition of objectives

For NRAs, the first step in advance of performing a cost-estimation study related to electricity interruptions is to set up a clear objective for the use of the results from the study. From CEER's point of view, these should be defined through a pre-study. CEER further believes that from a regulatory point of view the results could be used for:

- Setting financial incentives;
- Achieving general knowledge about customer valuation of continuity of supply; and
- Estimation of society costs for interruptions including spill over costs in the value chain.

For these purposes, CEER believes it is important to clearly define:

- Whether it is important to cover all types of customers or only some specific groups; and
- What kinds of interruptions (duration and frequency) which are important to investigate.

The objectives of the cost-estimation study will give guidance for what information and data should be collected and for the design and dimension of the study itself. Time and budget restrictions are closely connected to the objectives and from CEER's point of view they should therefore be evaluated and estimated during the pre-study defining the objectives. A very confined budget can also limit the choice of objectives, since it could make it impossible to achieve an objective.

2.3.3 Specification of customer groups

CEER recommends that customer grouping should be connected to the statistical classification of economic activities in the European community (NACE Rev.2). The NACE groups and sub-categories are explained in more detail in [3]. Based on this approach, CEER recommends the following grouping for a cost-estimation study regarding interruptions:

- Households;
- Commercial services (without infrastructure);
- Public services (without infrastructure);
- Industry (without large customers);
- Large customers; and
- Infrastructure.

Alternative groupings are possible, depending on the chosen objective of the cost-estimation study (e.g. whether to focus only on certain customer groups) and country-specific factors (e.g. the importance of agriculture for the national economy).

2.3.4 Choice of cost-estimation method

Electricity interruptions pose qualitative and quantitative consequences and costs on customers[12]. These costs can be identified by different approaches, explained below[13] and in Table 2.

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[12] Examples of qualitative consequences for end-user companies that are affected by electricity interruptions could be lost goodwill and lost confidence by their customers to deliver products in the future. For households, qualitative consequences could be lost comfort. It is important that these kinds of consequences are not forgotten.

[13] The methodologies briefly described here may in principal be used to reveal costs due to both electricity interruptions and voltage disturbances. Hence, both terms are included in the descriptions. In section 2.3.4, the recommendation on a survey-based approach (for some customer groups) refers to some of the methodologies described here.

In order to be able to check the accountability of the results, CEER recommends triangulation by using different cost-estimation methods on the same customer groups. One example is to collect cost-estimates for monetary costs with the Direct Worth method and to supplement with other methods that in addition cover non-monetary costs, e.g. contingent valuation (see alternatives "A" in Table 2).

When performing a cost-estimation study, CEER recommends using the methods presented in Table 2. These methods are briefly described below, while a more detailed description is available in [3]. For the customer group Households, the preferred solution is triangulation by using the methods marked by "A". An alternative solution is to use conjoint analysis, for which the pros and cons are described in [3].

		Households	Commercial services	Public services	Industry	Large Customers	Infrastructure
Cost-estimation Method	Direct Worth	A	A	A	A		
	Contingent Valuation	A		A			
	Conjoint Analysis	B					
	Preparatory Action Method	(A)					
	Preventative Cost Method		(A)	(A)	(A)		
	Direct Worth in Case Study					A	A
A – Alternative A B – Alternative B () – Possible to include/use							

Table 2: CEER recommendation on use of cost-estimation method.

Direct Worth Method:
This method is commonly used to estimate the monetary costs of electricity interruptions, and the data collection is based on surveys. Customers are asked to estimate the expenses which they incur due to a hypothetical or experienced interruption or voltage disturbance. Usually, several scenarios are presented to the customer and the customer has to specify the economic costs according to predefined cost categories. The scenarios must be understandable, realistic and accepted by the respondent.

Contingent Valuation:
Using Contingent Valuation studies, the respondent is presented with a hypothetical or experienced scenario of an electricity interruption or voltage disturbance, and asked for the willingness to pay to avoid it or willingness to accept compensation when it occurs, to be indifferent to the welfare losses in the scenario. The scenarios must be understandable, realistic and accepted by the respondent.

Conjoint Analysis:
This method is based on customers expressing their preferences for different hypothetical scenarios. Instead of asking directly for the costs, willingness to pay to avoid or willingness to accept certain interruptions or voltage disturbances, customers are asked to select the preferred option between pairs of hypothetical scenarios, or they may be asked to rank or rate a list of different hypothetical scenarios. Based on the choices, the costs are estimated indirectly through econometric models.

The Preparatory Action Method:
Using this method, the customer is asked to choose from a list of hypothetical actions which reduce the consequences of an electricity interruption or voltage disturbance. Each action is associated with a given cost. An action may be the purchase of candles in households. Note: this method asks for possible actions which are not implemented by the customers.

The preventative Cost Method:
This method measures customer expenditures to prevent or counteract the consequences of interruptions or voltage disturbances. The value of such purchases can be seen as an estimate for the costs of an interruption or a voltage disturbance that they seek to avoid. Note: this method asks for costs of preventative equipment which is already installed.

Direct Worth in Case Study:
For this recommendation which is listed in Table 2, the term applies for an intensive analysis of one or several “cases” in question. These “cases” are normally typical customers who can represent a large customer group or customers which have such complex consequences that the costs of interruptions and voltage disturbances have to be assessed on a case-by-case basis. These case studies can be based on both real experience and hypothetical scenarios.

2.3.5 Choice of normalisation factor and clarification of data needs

Cost estimates provided by respondents during a cost-estimation study are normally stated in absolute values for a given interruption frequency or duration. The data received from the respondents must be transformed into so-called normalised data in order to be able to compare data from different respondents, and to be able to group respondents with similar cost characteristics but perhaps with different electricity consumption. CEER, therefore, recommends that an electrical variable is chosen as the normalisation factor. More specifically, CEER recommends using a normalisation factor based on electricity demand or load as shown in [3], preferably a constant such as annual electricity consumption, average load, peak load or interrupted power. CEER recommends that the choice of factor is seen in connection with the use of the cost data and the available data in the actual project and within the current scheme for reporting interruptions and within the network and customer information systems. Hence, the final choice of the normalisation factor is highly country-specific.

2.3.6 Check for available data

For the survey-based approach presented in the flowchart in Figure 2, it is important to reduce the number of questions in the questionnaire to a minimum, while still revealing the necessary information, e.g. about customer characteristics. This is beneficial to the resources and time needed for the survey, and also to the expected response rates. For the case-based approach, the same is important in order to minimise the time needed for interviews and the time spent at the location of the business. Some data may be available within the context of the NRAs' data systems and data already reported from the distribution system operators (DSOs) and transmission system operators (TSOs).

2.3.7 Choice of conduction method

The conduction method is highly country-specific. CEER therefore recommends that the proposed methods have to be carefully considered by NRAs on a national level. In general, a proposed procedure to increase the response rate in postal/web surveys is to use a "phone – post/e-mail – reminder" approach. With this method, it can be ensured that the correct person is addressed, and normally that an acceptable response rate is obtained, in a cost-efficient way. Response rates, especially from households, can also be increased by implementing some kind of incentive for answering the questionnaires. CEER recommends approaching households by telephone since this gives higher response rates than mailed questionnaires and also reduces the risk of misunderstanding the questions. However, the telephone approach is not feasible if conjoint analysis is chosen as the cost-estimation method due the complex design of the questionnaire (see the SINTEF consultancy report [3] for more details). Commercial services, public services and industry should be approached either by web-based questionnaires. In order to ensure that the person with the most appropriate competence is addressed, the contact person should be identified by phone in a first step. Large customers and infrastructure are quite demanding, so cost-estimation should be based on case studies. Therefore, CEER recommends telephone or face-to-face interviews for these two groups.

		Households	Commercial services	Public services	Industry	Large Customers	Infrastructure
Conduction Method (Country specific)	Postal	B					
	Telephone	A				A	A
	Web	B	A	A	A		
	Face-to-face					A	A
A – Alternative A, see Table 2 B – Alternative B							

Table 3: CEER recommendations on use of conduction method.
"A" and "B" refers to the chosen conduction method as presented in Table 2 in section 2.3.4

The choice of conduction method is closely related to the choice of cost-estimation method presented in section 2.3.4, as well as to country-specific characteristics. The timing of the cost-estimation study is usually not dependent on the season of the year. Generally, a study can be conducted at any time of the year; still it is important to avoid expected busy time periods or holidays. The normal duration for conducting a survey is about 2 months, including reminders [3].

2.3.8 Design and test of questionnaires and scenarios

A questionnaire should contain two parts, one asking for the specific customer characteristics and one asking for the cost estimates for different interruption scenarios. These two elements are described in detail in [3], providing also examples of relevant questions and questionnaires.

CEER recommends testing all aspects of the survey: firstly in a focus group or in direct contact with the respondent, and secondly with a pilot study. The experience from the pilot gives NRAs and others a possibility to evaluate how realistic the estimates for the time, resources and budget needed for performing the final cost-estimation study are.

2.4 Recommendations for estimation of voltage disturbance costs

2.4.1 Cost-estimation approaches – flowchart and checklist

This section is based on part A of the SINTEF consultancy report on a cost-estimation study on voltage disturbance costs. However, here we focus on those steps in a cost-estimation study which are of most relevance for or require the involvement of NRAs when deciding to undertake a nationwide cost-estimation study, without providing an exhaustive description. The choice of steps to be described takes into account that consultants will be involved (as described in section 2.2). All steps are described in detail in [3]. Nevertheless, recommendations provided by CEER and the consultant should be adjusted for country-specific characteristics. CEER further recommends the a pre-study should be performed in advance of a main study in order to define the objectives for the main study and to clarify country-specific characteristics, budget and consultancy needs, possible funding partners, timeline and possibilities in general for the main study. Many of the issues presented in section 2.3 regarding electricity interruptions are also relevant to estimating the costs of voltage disturbances and are repeated, as appropriate, in this section.

Collecting data on interruption costs from customers is a challenge. Getting good quality data from customers on costs for voltage disturbances is even more difficult. It is quite straight forward for customers to notice when there is a total loss of power supply but to know the difference and recognise transient overvoltages, voltage swells, voltage dips, harmonics, unbalance, etc is something the vast majority of electricity customers is not capable of.

The typical sequence for a cost-estimation study is presented in the flowchart given in Figure 3. The flowchart is divided into a survey-based approach and a case-based approach. Survey-based approaches typically include designing a questionnaire which is sent out to a large representative sample. On the other hand, the case-based approach focuses on a few single cases to identify consequences of voltage disturbances for these typical cases. Both approaches could be used for all customer groups. However, with the exception of the industry customer group, CEER recommends using mainly either a survey-based or a case-based approach for each customer group (further background can be found in [3]). In the following, some of the important steps of the two approaches will be described. A checklist for each step and for each approach is described in Table 4.

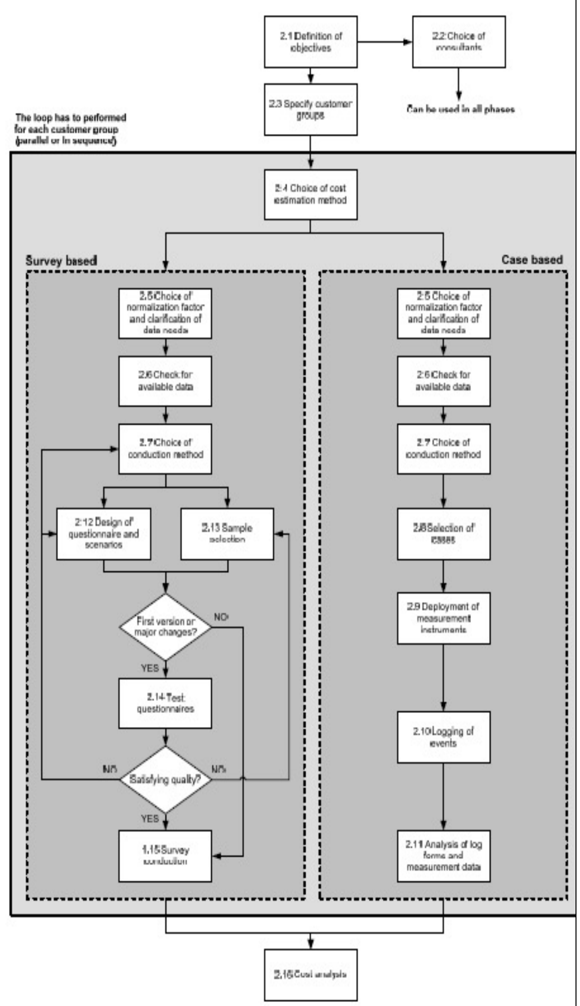


Figure 3 - Flowchart cost-estimation study of voltage disturbances

Step	Activities
Definition of objectives	Are the objectives of the study clearly defined?
Choice of consultants	Is it clearly defined in which project phases consultants should be used?
	Do the consultants have the right competences and resources?
Specification of customer groups	Are all electricity customers of interest and eventually their supply chain and customers covered?
Choice of cost estimation method	Are competences and resources available to implement the chosen survey and conduction method?
	Are competences available to analyze the data collected with the chosen method?
Choice of normalization factor and clarification of data needs	Are data available for the normalization factor or can they be collected from other public sources?
	Are data needs for covering the most important customer characteristics identified?
	Are data needs for developing a cost function or a regression analysis depending on several attributes identified?
Check for available data	Are available data sources checked?
	Are data available for the electricity consumption for each customer?
	Are data available for the contribution to national economy by each customer group and possible sub-samples?
Choice of conduction method	Can the expected response rates be achieved with the chosen conduction method?
Selection of cases	Are the selected cases typical for a larger group?
	Is the whole spectrum of customers covered?
Deployment of measurement instruments	Are proper measurement instruments chosen for the different cases and customers?
	Are the instruments located as close as possible to the Point of common coupling between customers and distribution system operator?
Logging of events	Is the log form designed to correspond with the voltage disturbances to be measured?
	Have the customer received information and training about his logging tasks?
Analysis of log forms and measurement data	Are there any log events corresponding in time with measured disturbances?
	Is it likely that the measured disturbance have caused the logged event? If so -> estimate the costs
Design of questionnaire and scenarios	The questionnaire covers the data needs, which data are not available from other sources?
	Construction of scenarios. Do the scenarios cover enough different attributes to estimate a cost function or to perform regression analysis (in case of conjoint analysis is chosen)?
	No questions included for data which can be obtained from other available data sources?
Sample selection	Is the sample size large enough to ensure statistically significant results?
Test of questionnaires	Were respondents able to give reliable cost estimates?
	Are the achieved response rates in the same order as used for the calculation of the sample size?
Survey conduction	Are resources available to conduct the survey in the envisaged time frame?
Cost analysis	Are competences and resources available to perform the quality assurance of data, normalization and estimation of cost data?

Table 4: Checklist for cost-estimation study of voltage disturbances

2.4.2 Definition of objectives

For NRAs, the first step when conducting a cost-estimation study related to voltage disturbances is to set up a clear objective for the use of the results from the study. From CEER's point of view, these should be defined through a pre-study. CEER further believes that from a regulatory point of view the basic aim of the results of a cost-estimation study on voltage disturbances is to get information on the consequences of voltage disturbances, as input on where to focus regulation, and further to prepare for (possible) penalty schemes. It must be considered whether it is important to cover all types of customers and phenomena, or a few specific groups or specific phenomena, only.

Experiences in several countries show that voltage dips, voltage swells, transient overvoltages, harmonic voltages and supply voltage variations can cause highest costs for customers.

The objectives of the cost-estimation study will give guidance on what information and data to be collected and on the design and dimension of the study itself. Time and budget restrictions are closely connected to the objectives, and from CEER's point of view should therefore be evaluated and estimated during the pre-study defining the objectives. A very confined budget can also limit the choice of objectives, since it could make it impossible to achieve an objective.

2.4.3 Specification of customer groups

CEER recommends that the customer grouping should be connected to the statistical classification of economic activities in the European community (NACE Rev.2). Still, customers included in a cost-estimation study related to voltage disturbances, need to some extent, knowledge about these disturbances and related consequences. Industrial companies, infrastructure customers and large customers having their own personnel with electricity and voltage quality knowledge may be able to deliver good quality answers to consequences and costs due to at least some voltage disturbances. However, even such personnel may not always have detailed knowledge about all aspects of voltage quality. Experiences so far indicate that not only household customers but even commercial services and public services have very little knowledge on voltage quality and how the different voltage disturbances affect or could affect them. CEER recommends specifying the customer groups as for interruption cost-estimation studies, i.e. using the following groups:

- Households;
- Commercial services (without infrastructure);
- Public services (without infrastructure);
- Industry (without large customers);
- Large customers; and
- Infrastructure.

In the consultancy study, SINTEF recommends focussing on industry customers, large customers and infrastructure customers, since they expect to find sufficient knowledge about voltage disturbances and their consequences for the operations in these customer groups. SINTEF also recommends asking the other customer groups, in a qualitative manner, of experienced consequences of voltage disturbances, if included in the study. Some cost estimates can be collected by presenting really simplified scenarios of voltage disturbances. CEER recommends that at least industry customers, large customers and infrastructure customers are included in cost-estimation studies on voltage disturbances. CEER further recommends that NRAs evaluate, during a pre-study, whether to include also additional customer groups when investigating costs due to voltage disturbances, taking into account the objectives of the study to be performed and country-specific characteristics.

2.4.4 Choice of cost-estimation method

Voltage disturbances can impose qualitative and quantitative consequences and costs on customers[14]. These costs can be identified by different approaches.

The best method for assessing data about voltage disturbances for all customer groups is a combination of a questionnaire survey and a limited number of case studies with logging of data. CEER recommends that case studies include both measurements of voltage quality data and logging of events, problems and costs/consequences in a journal at the customers, depending on the objective defined for the study. When performing a questionnaire survey it is necessary to do this with carefully selected simplified scenarios or with qualitative questions, without assessing the costs of voltage disturbances in quantitative terms. CEER recommends using the same survey-based methods for households (direct worth, contingent valuation), commercial services (direct worth), public services (direct worth, contingent valuation) and industry (direct worth) as given in the recommendations for estimation of interruption costs (see section 2.3.4 and Table 2). For industry, CEER recommends that NRAs consider whether to apply a survey-based or a case-based approach, or alternatively to use a case-based approach for some industry customers and the survey-based method for a representative sample of the whole group. Table 5 presents CEER's recommendations on whether to use a survey-based or a case-based approach for the various groups.

		Households	Commercial services	Public services	Industry	Large Customers	Infrastructure
Cost-estimation Method	Survey-based	A	A	A	B		
	Case-based				A	A	A
A – Alternative A B – Alternative B							

Table 5: CEER recommendations on use of cost-estimation method.

The case-based cost-estimation study as one part of the methods for assessing data about voltage disturbances focuses on a sample of companies and collects real time data about the voltage quality as well as the consequences of voltage disturbances for the customer. This approach is laborious, but it can ensure that the consequences can be assigned to different types of voltage disturbances, which is the great challenge in assessing the costs of voltage disturbances. The survey-based methods are, to some extent, explained in section 2.3.4; however, a more detailed description of all methods is given in [3].

[14] Examples of qualitative consequences for end-user companies that are affected by voltage disturbances could be lost goodwill and lost confidence by their customers to deliver products in the future. For households, qualitative consequences could be lost comfort due to, inter alia, flicker in the lights. It is important that these kinds of consequences are not forgotten.

Selection of cases for a case-based approach:
CEER believes that electro-technical education and preferably experience with voltage disturbances and related consequences is necessary to evaluate the consequences of voltage disturbances (either on the side of the consultant which is conducting the survey or by the customer who is being interviewed). In addition, cases should be selected where the customer seems interested in performing a study and therefore is willing to participate actively in the study.

2.4.5 Choice of normalisation factor and clarification of data needs

Cost estimates provided by respondents during a cost-estimation study are normally stated in absolute values for a given voltage disturbance. The data received from the respondents must be transformed into so-called normalised data in order to be able to compare data from different respondents, and to be able to group respondents with similar cost characteristics but perhaps with different electricity consumption. CEER, therefore, recommends that an electrical variable is chosen as the normalisation factor. More specifically, CEER recommends using a load-based normalisation factor (in kW) for voltage disturbances similar to electricity interruptions (as described in the recommendations for estimation of interruption costs, in section 2.3.5). If statistics of different voltage quality phenomena are available for different customer groups, it could also be possible to use the number of incidents and order of severity as normalisation factors per customer group; i.e. to calculate a cost per incident, cost per voltage dip of certain depth and/or duration, and so on. CEER recommends that the choice of factor is seen in connection with the use of the cost data and the available data in the actual project and within the current scheme for reporting voltage disturbances and within the network and customer information systems. Hence, the final choice of normalisation factor is highly country-specific.

2.4.6 Check for available data

For the survey-based approach presented in the flowchart in 2.4.1, it is important to reduce the number of questions in the questionnaire to a minimum, while still revealing the necessary information. This is beneficial to the resources and time needed for the survey, and also to the expected response rates. For the case-based approach, the same is important in order to minimise the time needed for interviews and the time spent at the location of the business. Data may be available within the context of the NRAs data systems and data already reported from the DSOs and TSOs.

2.4.7 Choice of conduction method

The conduction method is highly country-specific and the proposed methods have to be carefully considered by NRAs on a national level. CEER recommends conduction methods for survey-based studies to be consistent with those recommended for estimation of interruption costs (see section 2.3.7 and [3]). CEER recommends conducting case-based studies by face-to-face or telephone interviews and measurement of voltage disturbances with simultaneous logging of the consequences. Table 6 summarises CEER recommendations on conduction methods for various customer groups.

		Households	Commercial services	Public services	Industry	Large Customers	Infrastructure
Conduction Method (Country specific)	Postal	A					
	Telephone	A			A	A	A
	Web	A	A	A	B		
	Face-to-face				A	A	A
	Measurement/logging				A	A	A
A – Alternative A, see **Error! Reference source not found.** B – Alternative B							

Table 6: CEER recommendation on use of conduction method.
"A" and "B" refers to the chosen cost-estimation method as presented in ***Error! Reference source not found.*** *in section 2.3.4*

The choice of conduction method is closely related to the choice of cost-estimation method presented in 2.3.4, but also to country-specific characteristics. The timing of the study is usually not dependent on the seasons of the year. Generally, a study can be conducted at any time of the year; still it is important to avoid expected busy time periods or holidays.

2.4.8 Design and test of questionnaire and scenarios

CEER recommends a survey-based approach for the customer groups: households, commercial services, public services and partly industry customers. CEER further recommends a case-based approach be used for the customer groups: large customers and infrastructure customers and partly industry customers. Questions used for voltage disturbances can be developed as a stand alone questionnaire or be included in a joint questionnaire - if at the same time a survey on interruption costs is to be performed. However, when performing a questionnaire survey it is necessary to do this with carefully selected simplified scenarios as regards voltage disturbances. The need for simplifying voltage quality questionnaires is most pronounced for household customers and partly commercial services and public services but should be considered for all customer groups. It can be expected that almost all household customers have no competence in voltage quality. The questionnaire for household customers as well as commercial services and public services should be focussed more towards the consequences (from voltage disturbances) rather than the voltage quality parameters themselves.

Examples of questions and questionnaires are presented in [3]. CEER recommends testing all aspects of the survey; firstly in a focus group or in direct contact with the respondent, and secondly with a pilot study. The experience from the pilot gives NRAs and others the possibility to evaluate how realistic the estimates for the time, resources and budget needed for performing the final survey are.

2.5 Country specific characteristics

CEER recommends that the general advice on cost-estimation studies as provided in sections 2.3 and 2.4 and in [3], should be adjusted for certain country-specific characteristics. This is because the people and companies in different countries are using electricity for different purposes due to, *inter alia*, different climate. Therefore, they value the availability of electricity differently. The costs of voltage disturbances will also differ between countries due to different use of electrical equipment and appliances, different types of public and commercial services, industry customers, infrastructure customers. Also, the agriculture sector differs across Europe, including the level of automation. Different history of countries, various historical developments and culture are expected to influence the results as well. Any design of cost-estimation studies should therefore be adapted to country-specific characteristics. Some elements in the study approaches can be adapted irrespective of country-specific characteristics, while several elements may be quite different from country to country. CEER recommends investigating at least the following elements at national level, before performing a major cost-estimation study:

- Objective of the cost-estimation study for interruptions and voltage disturbances;
- Choice of customer groups and standard industrial classification;
- Data available for the normalisation factor(s);
- Worst case scenarios and use of electricity;
- Choice of interruption scenarios and voltage disturbance phenomena; and
- Conduction method and expected response rates.

These elements are explained in more detail in [3]. Furthermore, Chapter 3 shows how these elements are treated differently in three countries.

3 Real-life implementation of some past studies and their possible use for regulation

3.1 Introduction

This chapter provides real examples from three countries (Italy, the Netherlands and Norway) where cost-estimation studies have been conducted at national level for regulatory purposes. The intention is to describe how elements of and results from cost-estimation studies have been dealt with in real life. The experience is described separately for electricity interruptions and voltage disturbances, in sections 2.3 and 2.4, respectively. The various sub-topics are described according to the CEER recommendations outlined in this report; see the bullet point list below. The examples include regulatory use of results from cost-estimation studies.

The recommendations for studies on costs due to **electricity interruptions and voltage disturbances** include:

- Definition of objectives;
- Choice of consultants;
- Specification of customer groups;
- Choice of cost-estimation method;
- Choice of normalisation factor and clarification of data needs;
- Check for available data;
- Choice of conduction method (means by which the survey/case analysis is performed);
- Design of questionnaires and scenarios;
- Sample selection;
- Test of questionnaires;
- Survey conduction: how to conduct the survey/case analysis;
- Selection of cases;
- Analysis of cases; and
- Cost analysis.

In addition, as regards costs due to **voltage disturbances,** the recommendations cover a few additional aspects, specifically for case-based VQ studies:

- Deployment of measurement instruments;
- Logging of events; and
- Analysis of log forms and measurement data.

3.2 Continuity of supply

3.2.1 Italy

Background information:
A nationwide customer survey on interruptions - not referring to voltage disturbances - was carried out by AEEG (Autorità per l'energia elettrica e il gas) in 2003. Further information on the survey can be found in [5]. The results of that survey contributed to the definition and quantification of several regulatory mechanisms during the second tariff/quality regulatory period 2004-2007 and for the current tariff/quality regulatory period 2008-2011. Before the survey, a performance-based incentive (overall) regulation of distribution continuity of supply already existed since 2000, based on the cumulative duration of unplanned long interruptions (SAIDI, System Average Interruption Duration Index). The reward/penalty incentive scheme is symmetric and provides penalties (rewards) for under-performance (over-performance) with respect to the baseline SAIDI.

Definition of objectives:
The initial objective of the customer survey was to update the reward/penalty rate used in the performance-based incentive overall regulation of distribution continuity of supply. Theoretically, the continuity level is optimal when the sum of utility and consumer costs are minimised. This corresponds to having the same value of incremental costs for the utility to provide better continuity of service and of incremental costs for the customers due to poorer continuity. Further, theory can assume that a reward/penalty mechanism is a perfect driver for the decisions of a utility with perfect information on its input-output function (i.e. cost-continuity function).

In practice, it is difficult to choose the best continuity indicator. It is rather impossible to estimate a polynomial function of customer costs versus one continuity indicator, customer preferences (and consequently the cost they associate to electricity interruptions) can vary widely depending on their locations, use of electricity, etc. and the utility input-output curve can differ significantly depending on technical and geographic conditions.

Nevertheless, continuity indicators are currently adopted by many countries. It is possible to estimate an average customer cost for a selected continuity indicator and it is possible to differentiate this estimation for a set of parameters (e.g. for the size of municipality, distinguishing rural, intermediate and urban areas). Further, utilities have sufficient information on their input-output functions to select best-performing capital and operational decisions. The combination of these factors allows regulators to promote a move towards the optimality region, where costs of network services and benefits of continuity are optimised for customers.

As a matter of fact, the results of the Italian customer survey were later used also as a reference for other regulatory mechanisms which have a lesser impact than the performance-based incentive regulation of distribution continuity of supply in terms of financial amounts for the utilities, but could end up being significant for individual customers:

- performance-based incentive (overall) regulation of transmission continuity of supply; and
- guaranteed standard (individual) with automatic compensations for customers suffering a very long interruption.

A summary description of the use of the survey results for policy-making is reported at the end of this section.

Choice of consultants:
In 2002, AEEG had no practical experience on how to set up a survey. On the other hand, attitudes of Italian electricity customers with respect to surveys were known, as customer satisfaction surveys are carried out yearly since 1998. The decision on consultants and consultancy activities was therefore to have i) a technical-scientific support on how to design and carry out the survey and how to assess its results; and ii) practical support by a company specialised in market research and surveys for conducting the survey and initially treating the results.

Specification of (sectors and) customer groups:
Two sectors were considered: domestic and business electricity users. The 'business' sector was further split into three groups: industry, commercial services (shops) and other commercial and trading services (e.g. banks). The last two groups turned out to be, however, extremely heterogeneous. For this reason, sub-samples were identified for single segments of sub-sector activity (wholesale commerce, retail commerce, hotels/restaurants, and so on).

Choice of cost-estimation method and choice of conduction method:
Interviews were conducted directly at the home of the residential respondents and at the productive units of the business respondents (i.e. face-to-face interviews) and lasted on average 30 minutes. This is a rather common survey method in Italy, especially when dealing with complex surveys. In Italy, response to postal interviews is extremely limited and this would have led the sample to self-select, even when performing reminder and follow-up operations.

The Italian survey on interruption costs was based on the contingent valuation approach and also implemented a Direct Worth approach. The analyses included consumers' Direct Costs (DC) and use of results was based on the valuation of consumer Willingness to Pay (WTP) and Willingness to Accept (WTA).

Choice of normalisation factor:
The already adopted (since 2000) continuity indicator for distribution continuity was System Average Interruption Duration Index (SAIDI), expressed in minutes of interruptions for low voltage customer per year. For transmission continuity (not yet regulated and taken into account at the time of the survey), the main indicator is Energy Not Supplied (ENS).

WTA and WTP normalised values were expressed in €/kWh not supplied for long unplanned interruptions (1 hour, 2 hours, 4 hours, 8 hours) and in €/kW not supplied for short unplanned interruptions (3 minutes).

Check for available data:
The samples represented the Italian low voltage end-user population, with different network features (high, medium and low population density areas). All together, the populations covered an extremely large share of consumers in terms of number (97% of total consumers) and accounted for approximately half of the total Italian electricity consumption. The reference universe for the domestic sector was composed of Italian families, 22 million (less than the number of household customers, which includes other residential buildings for holidays, etc.). The reference universe for the business sector was in the order of 3.8 million.

A first indicator of energy use by consumers in Italy is the contractual available power in kW: all residential consumers fall within the 1.5 – 6 kW band. The highest concentration is at the 3 kW value, which is the default level for domestic power.

The average household consumption was lower than 3000 kWh per year (now slightly above 2000 kWh per year), while business averages were approximately ten times higher.

Scenarios:
Each respondent was presented with a 2-hour interruption scenario, characterised by a time of day in which it occurred and a day of the week (work-day, holiday, Saturday). In order to investigate the impact of the interruption's duration, the respondent was required to estimate how much more or less (in percentage terms) would the afore-stated damage be if the interruption lasted 3 minutes, one hour, 4 hours or 8 hours.

Sample selection:
The survey was targeted to reach 1100 domestic users and 1500 business customers: 500 industrial customers, 450 commercial services (shops) and 550 other commercial and trading services.

The possible problem regarding estimation of response rate by customers was treated by AEEG by giving the evaluation to the market survey company: a contractual clause requested a pre-defined result - the figures above with at least 80%-completed questionnaires.

Even after censoring (suppression of interviews featuring anomalous extreme values or missing values), the number of replies for the analysis of results slightly decreased to 909 for the residential customer group and to 1217 for the business sector (percentage of useful answers higher than 80%).

The sample was further sub-stratified, according to the variables shown in **Error! Reference source not found.**.

Variables	Household customers	Business customers
Number of interviews	1100 face to face	1500 face to face (500 in the industrial sector and 1000 in commerce and other services)
Size of the company	NAP	On the basis of number of employees, in 4 classes: 1-2, 3-9, 10-49 and 50-499
Geographic macro-area	North West, North East, Centre, South and Islands	North West, North East, Centre, South and Islands
Size of municipality	Metropolitan areas, Large, Medium, Small locality	Metropolitan areas, Large, Medium, Small locality

Table 7: Sub-samples of the Italian interruption cost survey
Source: [5]

Survey conduction:
The survey was conducted during one month: September 2003. The first utilisation of results was implemented for the second tariff/quality regulatory period 2004-2007 (regulatory order in January 2004), as illustrated in the following section.

Cost analysis and use of the survey results in regulation:

Performance-based incentive (overall) regulation of distribution continuity of supply
Setting the reward/penalty rates (one for households and one for business customers) for this regulation was the main objective of the survey on interruption costs. Translating the information coming from the survey into a few numerical values required an effort of synthesis and, in part, also discretional decision-making.

The reference numbers used by the regulator were the normalised values of WTP and WTA. WTP was systematically less than WTA and the disparity between the two was often extremely significant: WTA was 4 to 7 times higher than WTP. Given the extensive spread between the WTP and WTA values, each sector is presented in Figure 4 (1-hour interruption scenario) with a range of values consisting of:

- A lower limit, the WTP parameter; and
- An upper limit, the (WTP+WTA)/2 parameter.

This range may be interpreted as the interval of values within which the regulatory body may act in establishing unitary incentive rates.

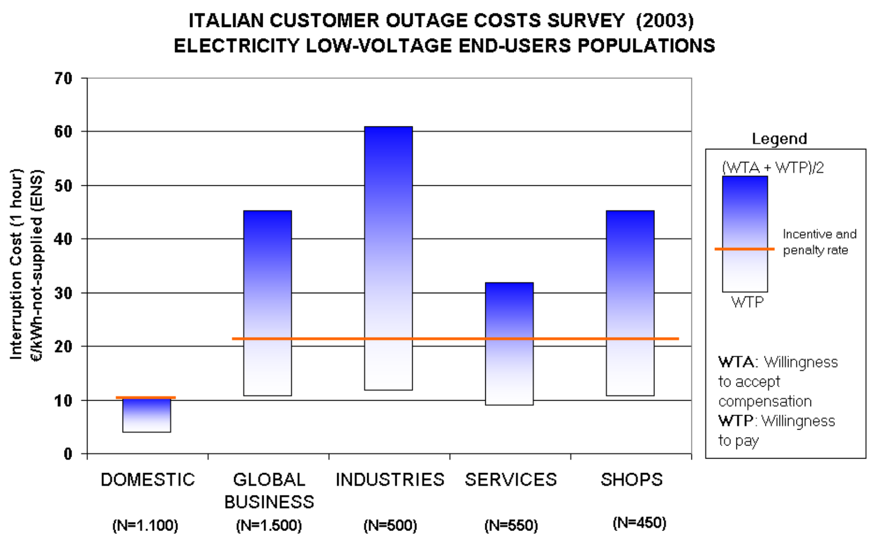


Figure 4 - Treating the volatility in survey results, Italian interruption cost survey
Source: [5]

Given the large difference in numerical values, especially for business customers, a prudent choice was made for business (21.6 €/kWh not supplied). The decision to select a value towards the lower end of the range makes allowance for the relatively low levels of willingness to pay and is dictated by a principle of "caution". The incentive rate for domestic consumers was set, instead, in the upper range of the interval [WTP ÷ (WTP+WTA)/2] (10.8 €/kWh not supplied). Further, these figures were differentiated (**Error! Reference source not found.**), in order to promote a stronger impact of the continuity regulation in territorial districts with bad continuity indices.

Customer group	Reward/penalty rate Unplanned interruption €/kWh ENS	Reward/penalty rate Unplanned interruption €/kWh ENS	Reward/penalty rate Unplanned interruption €/kWh ENS
	Below the long term SAIDI target (differentiated urban/mid/rural)	Between the long term SAIDI target and 3 times SAIDI target (differentiated urban/mid/rural)	More than 3 times SAIDI target (differentiated urban/mid/rural)
Business (all customers except residential)	14.4	**21.6**	28.8
Residential customers (households)	7.2	**10.8**	14.4

Table 8: Setting the reward/penalty rate for SAIDI indicator in Italy (2nd tariff/quality regulatory period, years 2004-2007) Source: AEEG regulatory order 4/04

In the third regulatory period (2008-2011), AEEG slightly reduced the values for SAIDI reward/penalty rates, as fine-tuning of the regulatory scheme and also in order to take into account the introduction and the complementary role of the SAIFI+MAIFI indicator in the performance-based incentive (overall) regulation of distribution continuity of supply.

<u>Performance-based incentive (overall) regulation of transmission continuity of supply</u>
The approach for this regulation is conceptually similar to the already described case for distribution continuity. In this case, only one reward-penalty rate is adopted for the ENS (15 €/kWh). As a matter of fact, the weighed average of costs for LV households (less than 25% of Italian electricity demand) and costs for business (assuming that figures for LV industry can also represent MV and HV industry, as survey results were not available for MV and HV industrial loads) would be higher than 20 €/kWh. Nevertheless, this setting has to take into account a complementary role of the “frequency” indicator NOU (Number of Interruptions for high voltage network Users) for determining rewards and penalties for the transmission network operator. Further information about this regulation and the rationale for regulatory choices are available in [7]. Also in this case, the final decision tended to be cautious, taking into account that a “new regulation” was just starting in 2008. It is interesting to mention that AEEG informed, during the consultation process, about the approach of Ofgem[15] in regulation of transmission continuity for National Grid (reliability incentive scheme, prepared in 2004 and starting in 2005): Ofgem set a reward/penalty rate at 33 £/kWh, £ as of year 2005. Ofgem clearly stated in both irs consultation and decision that it did not derive the incentive structure from an estimate of VOLL (Value of Lost Load), but rather to stimulate management attention on the costs of disruption to consumers and to encourage a strategy minimising the overall risk of an interruption in supplies [8].

[15] Ofgem: Office of the gas and electricity markets, Great Britain energy regulator, www.ofgem.gov.uk.

Guaranteed standard (individual) with automatic compensation for customers suffering a very long interruption

In order to protect customers against very long interruptions, and to complete continuity regulation also for exceptional events (interruptions of this type are considered "force majeure" and excluded from regulation), AEEG introduced in 2007 new standards on the maximum duration of very long interruptions per single customer, with automatic compensations. The proposal was initially submitted for public consultation in May 2005 and it underpinned a significant debate with network operators. In a second document in June 2006 with more advanced proposals, AEEG proposed to introduce new standards on the maximum duration of very long unplanned and planned interruptions.

The guaranteed standards in force from 2009 are oriented at protecting and safeguarding customers and at stimulating DSOs to define and carry out the necessary measures to reduce the length of interruptions both in normal circumstances and during exceptional events. Long unplanned interruptions during "normal and exceptional condition" shall be restored within 8 (12, 16) hours for LV customers and within 4 (6, 8) hours for MV customers in urban (mid, rural) areas.

DSOs pay customers the initial basic compensation if the threshold is exceeded and additional compensation based on the additional length of the interruption up to a cap (to limit the financial risk of DSOs). Responsibility lies also with the transmission operator for HV interruptions and a socialised compensation fund is used to pay compensation for force majeure events. The compensations are differentiated between domestic and non-domestic customers. The compensation value for household customers is 30 € (initial basic amount), plus additional compensation 15 € every 4 hours. For non-domestic customers, values are five times higher, consistently with the ranges of survey results previously shown in Figure 4. For large non-domestic customers (> 100 kW), the compensation depends on contractual power.

The 2003 survey was not intended to provide information for rare interruptions lasting more than 8 hours. However, survey results were used in the consultation process as background information for proposing and setting the compensation. Average electricity consumption for households in Italy is higher than 2000 kWh/year, which could correspond to 6 kWh/day for the sake of simplicity. The automatic compensation for a 24-hour interruption is 75 - 60 - 45 € for a domestic customer in an urban - mid - rural district, which corresponds to 12.5 - 10 - 7.5 €/kWh not supplied.

3.2.2 The Netherlands

Background information:

A nationwide customer survey on interruptions was carried out by SEO Economic Research (hereafter SEO) in 2004 and updated by SEO in 2009. The present case study only describes the customer survey carried out in 2004. The update in 2009 realigned key variables with current economic developments. It did not include a new customer survey.

The regulatory system for regional electricity network operators in The Netherlands is based on yardstick competition. To avoid that network operators over-emphasise cost efficiency, incentive-based quality regulation was introduced in 2005. This regulatory framework puts a price tag on the quality of the electricity supply, providing a financial stimulus for network operators to supply the right level of quality. The question is: what is the right level of quality? Only the consumer can answer this question, with the duration and frequency of electricity interruptions being the relevant properties of continuity of supply.

The Dutch regulatory system for quality combines elements of yardstick regulation with consumer valuation of electricity interruptions. The system is designed in such a way that it pays for network operators to improve their track record in terms of the duration and frequency of electricity interruptions. They may charge higher tariffs, as long as this higher level of quality increases the welfare of consumers and companies.

The scope of the Dutch system of quality regulation is the low- and medium voltage network. It does not include large consumers. Force majeure incidents are also excluded.

Objectives:
The aim of the customer survey was to put a price tag on the quality of electricity supply. For this purpose, two properties of electricity supply were considered: the duration and the frequency of interruptions. Voltage quality and commercial quality were not included in this survey. More precisely, the indicators used in this survey were:

- System Average Interruption Duration Index (SAIDI);
- System Average Interruption Frequency Index (SAIFI); and
- Consumer Average Interruption Duration Index (CAIDI).

Choice of consultants:
The customer survey was performed by SEO.

Specification of customer groups:
The analyses were carried out separately for small and medium-sized (SME) companies and for households. The sample of households was drawn from three different large panels to ensure the inclusion of customers from all network operators in The Netherlands. The sample was representative of the Dutch population in terms of gender, age, income, etc. The sample of SME-sized firms was drawn based on the registers of the Chamber of Commerce. It was a stratified sample to ensure a representative sample of firms in terms of business size and economic sector.

Choice of cost estimation and conduction method:
The survey method was (for both groups, companies and households) a web-based survey-based on questionnaires using the conjoint analysis. For the SME-firms, a ready-made panel did not exist. Potential participants were first approached by telephone and afterwards sent the link for the web-based survey by e-mail.

Design of questionnaire and scenarios:
The typical conjoint analysis question presents each respondent with a number of commodity descriptions or situations (vignettes: cards describing fictitious but not unrealistic situations) that differ according to the attributes described. Survey respondents are then asked to rank and/or rate the desirability of each vignette. The inclusion of a price, as one of the attributes, enables the derivation of implicit prices for each of the other attributes. Conjoint analysis does not directly ask for willingness to pay, but requires that respondents rank possible outcomes from most preferred to least preferred, while several attributes of the good are varied. This results in a relative value, in the sense that the expressed value depends upon the other alternatives that have to be ranked. An example of attributes included is presented in Table 9.

Attributes	Values
Frequency of interruptions	Multiple-interruption vignette: once a week to once every 20 years
Duration of the interruption	30 s, 5 minutes, 15 minutes, 30 minutes, 60 minutes, 2 h, 4 h, 12 h, 24 h
Day of the week	Monday to Sunday and national holiday
Part of the day	Morning, afternoon, evening and night
Season	Spring, summer, autumn and winter
Warning in advance	Yes (within 3 days), No
Change in electricity bill	Single-interruption vignette: varying from a discount of 0–15%
	Multiple-interruption vignette: varying from a raise of 50% to a discount of 25%

Table 9: Values of the attributes, The Netherlands

Due to the large amount of possible combinations of duration and frequency, it would have been impossible for respondents to rate vignettes including both a duration and frequency attribute. The survey therefore consisted of two sets of vignettes, both to be evaluated by the respondents. The first set assumed one electricity interruption per year. These single-interruption vignettes were designed to estimate the cost effects of duration and characteristics such as time of day, day of week, season, and so forth. The second set assumed a fixed 2-hour interruption, with the goal of collecting data to estimate the cost effect of frequency. This means that the vignettes in this second set were multiple-interruption vignettes. The price variable of all vignettes was expressed as a discount or mark-up percentage on the respondent's monthly electricity bill. SEO created 136 single-interruption vignettes and 60 multiple-interruption vignettes.

As part of the questionnaire, respondents were asked for th specific customer characteristics (such as the yearly electricity bill).

An example of a duration-vignette:

Duration of the interruption	2 hours
Day of the week	Wednesday
Part of the day	In the afternoon (12 pm till 6 pm)
Season	Summer
Warning in advance	Without warning
Change in electricity bill	5% discount
Rating mark	-

An example of a frequency-vignette:

Number of interruptions	1 interruption in 10 year
Change in electricity bill	25% increase
Rating mark	-

Sample selection:
The response rate for households was 27% (12.409 households) and was a representative sample of the 7 million households in The Netherlands. The response rate of companies was 6.5% (2.481 companies) and was a representative sample of the 800.000 SME-companies connected to the low-voltage network.

Test of questionnaires:
The final set of questionnaires used in the study was chosen after a pilot survey covering 200 companies and 690 households. Subsequently, two large samples were drawn in the summer (May/June) and in the winter (of December/January). To test whether customer perception with respect to the energy supply differs between seasons, the sample was spread evenly over the warm and cold seasons. No significant difference in valuation was found between seasons.

Cost analysis:
The research provided an estimate of the demand curve in relation to power failures by measuring (hypothetical) preferences. This was done by means of a regression analysis based on the rating of the vignettes. The regression provided the coefficients of the attributes (see **Error! Reference source not found.**) for both duration and frequency of power interruptions. These regressions were interpreted as a first-order approximation of the customer's indirect utility function. By means of the implicit function theorem, the indirect utility functions were rearranged to form compensation functions for different durations and frequencies of power interruptions. This compensation function shows the extent to which households and SME-companies wish to be compensated for interruptions of different frequency and duration.

Figure 5 shows the compensation level of four different situations, for both households and companies. Only in situation 4 does the consumer wish to be compensated for every interruption; in the remaining three situations the consumer either requires compensation or is even willing to pay for a worsening of the quality of electricity supply. The regression analysis showed that the relationship between consumer preferences (in terms of compensation) and the properties of the quality of supply (continuity of supply; frequency and duration of interruptions) is best represented by a logarithmic function.

Situation 1: very few interruptions, each of very short duration	
Companies: In this situation, each company experiences less than one interruption in the period of 12 years, which lasts for less than 14 minutes. Example: If companies were to experience an interruption once in the 15-year period, lasting less than 14 minutes, they would be willing to pay EUR 68.90 per annum for this.	Households: In this situation, each household experiences less than one interruption in the period of 8 years, which lasts for less than 21 minutes. Example: If companies were to experience an interruption once in the 15-year period, lasting less than 21 minutes, they would be willing to pay EUR 9.60 per annum for this.
Situation 2: very few interruptions, each of very short duration	
Companies: In this situation, each company experiences interruptions more than once in the period of 12 years, but the interruption lasts for less than 14	Households: In this situation, each household experiences interruptions more than once in the period of 8 years, but the interruption lasts for less than 21

minutes. Example: If companies were to experience an interruption more often than once in the 12-year period, lasting less than 14 minutes in total, no compensation would be required.	minutes. Example: If households were to experience an interruption more often than once in the 8-year period, lasting less than 21 minutes in total, no compensation would be required.
Situation 3: very few interruptions, each of very short duration	
Companies: In this situation, each company experiences less than one interruption in the period of 12 years, but the interruption lasts for longer than 14 minutes. Example: If companies were to experience an interruption once in the 15 year period, lasting two hours, they would be willing to pay EUR 67 .90 per annum for this.	Households: In this situation, each household experiences less than one interruption in the period of 8 years, but the interruption lasts for longer than 21 minutes. Example: If households were to experience an interruption once in the 15-year period, lasting two hours, they would be willing to pay EUR 9.00 per annum for this.
Situation 4: very few interruptions, each of very short duration	
Companies: In this situation, each company experiences more than one interruption in the period of 12 years, and the total interruption lasts for longer than 14 minutes. Example: If companies were to experience three interruptions a year, lasting two, four and five hours, they would wish to receive compensation for this amounting to EUR 206.50 per annum.	Households: In this situation, each household experiences more than one interruption in the period of 8 years, and the total interruption lasts for longer than 21 minutes. Example: If companies were to experience three interruptions a year, lasting two, four and five hours, they would wish to receive compensation for this amounting to EUR 25.30 per annum.

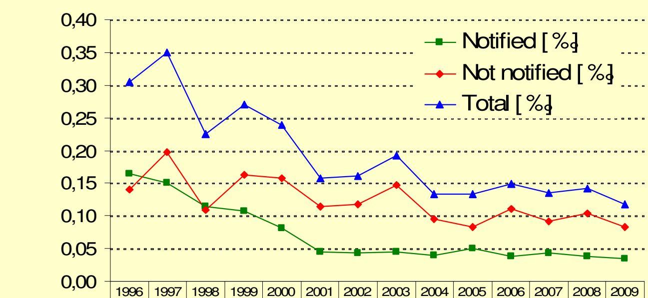
Figure 5 - Prices tags in four different scenarios
Source: B.E. Baarsma and J.P. Hop (2009), Pricing power outages in the Netherlands, Energy, vol. 34(9), pp. 1378-1386.

Use of the survey results in regulation:
The results of the survey have been used in all regulatory periods since 2007. The valuation function is used to derive the quality performance of each network operator, based on the delivered quality (in terms of number and average length of interruptions, SAIFI and CAIDI). The average quality performance of all network operators is used as a 'standard quality performance'. A network operator may increase its tariffs if it outperforms this norm, but has to reduce its tariffs if it underperforms relative to the norm.

3.2.3 Norway

Background information:
The most recent nationwide cost-estimation study (customer survey) in Norway on costs due to electricity interruptions was a joint survey including costs on electricity interruptions and voltage disturbances. The survey was conducted during 2001-2002. Before that, a survey was conducted during 1990-1991 on costs due to electricity interruptions, only (and even one during the 1970s as well). Customer costs evolve with time, as do estimation techniques, and in 2008, a new pre-study was performed. The pre-study was financed by NVE (Norwegian Water Resources and Energy Directorate), solely. Based on the results from that pre-study; a new nationwide cost-estimation study is now underway, including costs due to electricity interruptions, voltage disturbances and rationing, planned to be finalised during 2012. Below, examples will be described with reference to the survey from 2001-2002. Further information on the survey can be found in [3] and [4]. The project description for the ongoing study is included in Annex 3.

Quality of electricity supply regulation has in many countries typically started with monitoring and reporting of continuity of supply. The Norwegian quality regulation has been developed gradually since the Energy Act entered into force in 1991 (beginning of deregulation). Revenue cap (incentive) regulation of the DSOs and the TSO was introduced in 1997, which put strong incentives on them to reduce their overall costs. To avoid cost-efficiency resulting in a reduction of quality of supply levels over time, sufficient requirements and incentives for the quality of supply levels are necessary. Mandatory monitoring and reporting of long interruptions (> 3 min) started in 1995 and standardisation of the estimation of energy not supplied in 2000. This laid the foundation for introducing *quality dependent* revenue caps (and cost of energy not supplied - CENS) in 2001. Mandatory reporting of short interruptions (≤ 3 min) and interrupted power became mandatory in 2006. Previous studies have estimated total costs of short interruptions to be in the same order as long interruptions on an annual basis when taking into account the frequency of occurrence, and that the costs are highly time dependent on a weekly and daily basis [4]. The incentive-based regulation on continuity of supply has been modified several times since 2001, in particular from 2003, 2007 and 2009. From 2007, a regulation for direct (financial) payment to customers who experience very long interruptions (>12 hours) has also been in place. The Norwegian energy legislation also mandates NVE with legal powers to regulate voltage quality.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Notified [‰]	0,17	0,15	0,11	0,11	0,08	0,04	0,04	0,05	0,04	0,05	0,04	0,04	0,04	0,03
Not notified [‰]	0,14	0,20	0,11	0,16	0,16	0,11	0,12	0,15	0,09	0,08	0,11	0,09	0,10	0,08
Total [‰]	0,31	0,35	0,22	0,27	0,24	0,16	0,16	0,19	0,13	0,13	0,15	0,13	0,14	0,12

Figure 6 - Electricity interruptions for all Norwegian end-users from 1995 to 2009
Rrepresented by energy not supplied relative to energy supplied (per thousand). Note that revenue cap regulation was introduced from 1997 and incentives regarding continuity of supply from 2001.

Definition of objectives:

The Norwegian financial incentive-based regulation on continuity of supply gives the DSOs and the TSO economic motivation to ensure an optimal resource allocation when all minimum requirements are complied with. This influences decisions regarding, *inter alia*, planning, investments in new infrastructure, operation, maintenance, contingency planning, etc. The objective is to achieve the most optimal level of continuity of supply for society as a whole, taking into account all relevant cost elements. The current incentives in place are based upon the results from the above-mentioned survey conducted in 2001-2002. The customer costs vary between different customer groups, and they are highly time dependent. The costs related to investments to reduce the extent of interruptions will, on the other hand, depend significantly on the location of the customers' connection to the power system, including network topology, geography, climate, etc. From the regulator's point of view, it is important that decisions influencing continuity of supply are also based on cost-benefit analyses; i.e. the costs related to reducing the extent of interruptions must be lower than the future decrease in customers' interruption costs due to the investment.

The objective of the survey conducted in 2001-2002 was to contribute to increased knowledge of socio-economic costs related to interruptions and voltage disturbances, providing the necessary basis and incentives for authorities, DSOs, the TSO, and customers to contribute to a socio-economic optimal level of quality of supply. The results from the survey were aimed to be able to serve various purposes related to planning, operation and maintenance of the power system, further development of the regulation, load shedding, etc. The data needed for this were found to be (as identified by a pre-study):

- Costs of long interruptions;
- Costs of short interruptions;
- Costs related to voltage disturbances;
- Costs related to partial interruptions/load shedding;
- Customers perceived quality of electricity supply; and
- Consumer flexibility regarding price vs. quality of electricity supply.

The scope of the survey was to collect data for all types of customers aggregated to six customer groups, see further below regarding specification of customer groups. The survey conducted in 2001-2002 was partly financed by the Research Council of Norway (www.forskningsradet.no)[16], and further jointly by NVE, a trade organisation for, *inter alia*, DSOs, the TSO, one DSO, a trade organisation for the processing industry and one large company which is both a large customer and partly a DSO. Still, NVE was the main financial contributor together with the Research Council.

Choice of consultants:
NVE had the same understanding of the necessary competence needed to perform a cost-estimation study, as CEER recommends in section 2.2. In order to ensure this competence profile for the Norwegian survey from 2001-2002, the consultants chosen were SINTEF Energy Research (www.sintef.no) in cooperation with SNF, Institute for Research in Economics and Business Administration (www.snf.no). For the current cost-estimation study in Norway and for the same reasons, the consultants chosen are SINTEF and ECON Pöyry (www.econ.no).

Specification of customer groups:
During a pre-study in 2000, it was recommended to focus on six customer groups; agriculture, residential, industry, commercial, public and large industry. These customer groups are connected to the statistical classification of economic activities in the European Community (NACE codes), or standard industrial classification (SIC). The survey conducted in 2001-2002 therefore mapped interruption costs for customers within these six groups. **Error! Reference source not found.** shows the interruption costs with energy not supplied as a normalisation factor, applicable for regulation in 2003 to 2006[17], and also the corresponding interruption costs applicable for the regulation in 2001 and 2002 based on the former survey conducted in 1990-1991. The data in this table indicate what you might gain from separating in six customer groups compared to only two groups.

[16] Funding for R&D can be allocated by the Research Council of Norway if applied for.

[17] In 2007 and 2008, these rates refer to 2002 cost-level, where CPI adjusted according to 2007 and 2008 cost-level, respectively.

<table>
<tr><th colspan="3">Based on survey conducted in 2001-2002
Rates applicable in regulation in 2003-2006</th><th colspan="3">Based on survey conducted in 1990-1991
Rates applicable in regulation in 2001-2002</th></tr>
<tr><th>Customer group</th><th>Non-notified interruption
(duration 1.3 h), NOK/kWh ENS</th><th>Notified interruption
(duration 2.85 h), NOK/kWh ENS</th><th>Customer group
NOK/kWh ENS</th><th>Non-notified interruption
NOK/kWh ENS</th><th>Notified interruption</th></tr>
<tr><td>Residential</td><td>8</td><td>7</td><td rowspan="2">Residential and agricultural customers</td><td rowspan="2">4</td><td rowspan="2">3</td></tr>
<tr><td>Agriculture</td><td>15</td><td>10</td></tr>
<tr><td>Industry</td><td>66</td><td>46</td><td rowspan="4">Industrial and commercial customers
(all but res.& agr.)</td><td rowspan="4">50</td><td rowspan="4">35</td></tr>
<tr><td>Commercial</td><td>99</td><td>68</td></tr>
<tr><td>Public sector</td><td>13</td><td>10</td></tr>
<tr><td>Large industry</td><td>13</td><td>11</td></tr>
</table>

Table 10: Comparison of survey results for the Norwegian surveys conducted "1990-1991" and "2001-2002". The numbers show an increase in the level of interruption costs, and the gain by extending the number of customer groups

Choice of cost-estimation and conduction method:
A survey-based approach was chosen for the cost-estimation study during 2001-2002. The survey was conducted by post (i.e. mailed questionnaires). Triangulation of methods was performed using the following cost-estimation techniques: direct worth (DW), the contingent valuation; willingness to pay (WTP), and to some extent the preparatory action method. The DW approach yielded significantly larger values than the contingent WTP valuation, as in accordance with other surveys, as well as from other markets [3]. WTP tends to be underestimated, while DW tends to be overestimated. The ration DW/WTP is about 5-12 for the interruption scenarios in the commercial sector and 6-8 in the industrial sector, while the ratio is 2-3 in the residential and agriculture sectors. Due to difficulties in quantifying the deviation between reported and real WTP, the estimated WTP was introduced as M = (DW+WTP)/2. This was done for each respondent. If the respondent reported only DW or only WTP, M was set at this one value for this respondent [3].

Choice of normalisation factor and clarification of data needs:
NVE introduced reporting of long interruptions from 1995 focusing on (but not only) energy not supplied for all end-users connected at all voltage levels affected by incidents at voltage levels above 1 kV. Energy not supplied was also chosen as the normalisation factor when introducing quality dependent revenue caps from 2001 (based on the survey from 1990-1991). The incentives apply for all DSOs and the TSO regarding customers connected to all voltage levels, but due to incidents above 1 kV. When updating the scheme with new interruption costs and extending the number of customer groups from two to six from 2003, it was chosen to continue using energy not supplied as a normalisation factor.

Electricity consumption in Norway (heating in particular) is highly dependent on outdoor temperatures. Consequently, temperature dependent load profiles have been established for all the surveyed customer groups and for all climatic zones. For the purpose of estimating normalised cost data per respondent, the load profiles were combined with information from the questionnaire about yearly electricity consumption, category of end-user and climatic zone. A more detailed description can be found in [3].

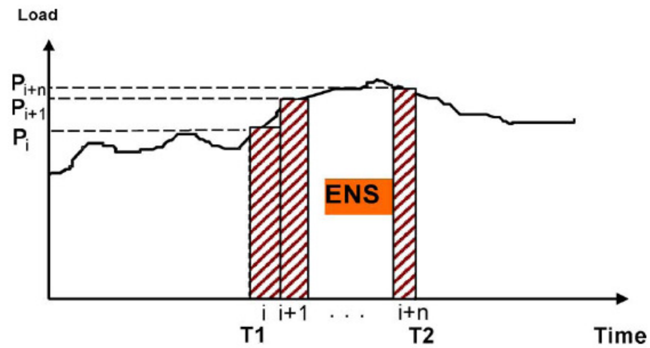


Figure 7 - Approximation of energy not supplied based on hourly average load

From 2009, the incentive-based regulation on continuity of supply was extended to include short interruptions and to take into account the costs' time dependency. To incorporate short interruptions (≤ 3 minutes) the cost rates were established as a function of the interruption duration. The customer survey conducted in 2001 – 2003 provided sufficient interruption cost data for six customer groups related to hypothetical interruptions of 1 minute, 1 hour, 4 hours and 24 hours duration (8 hours for the residential group). These data are normalised per respondent in the survey with the corresponding interrupted power at the reference time [4]. The interrupted power is defined as the estimated power in kW that would have been supplied at the time of interruption if the interruption had not occurred (equivalent to P_i in Figure 7). The normalised cost data are used to establish continuous cost functions based on linear interpolation between the discrete surveyed data (arithmetic mean). This will be presented below regarding the current incentive-based regulation.

Design and test of questionnaires and scenarios:
Design of questionnaires involves tradeoffs between details on the one hand, and response rates on the other. The final set of questionnaires used in the study was chosen through an iterative process which included a pilot survey covering two customer groups. Table 11 presents an overview of the different main parts of the questionnaires.

I	INFORMATION ABOUT THE RESPONDENT AND ELECTRICITY CONSUMPTION
	SIC[1] business sector, business size, working hours, type of offices, other energy resources, etc. Yearly electricity consumption in kWh and NOK[2]
	Electricity usage. Perceived quality of electricity supply (interruptions, voltage disturbances and information/notification)
II	COST OF INTERRUPTIONS AND VOLTAGE DIPS
	Total costs in NOK for different durations of incidents occurring at reference time: 50% dip in 1 sec., interruption of 1 min., 1 hour, 4 hours, 24 hours[3]
	Costs divided into A) Damage of equipment, spoiled goods or raw material etc., B) Loss of production, C) Extra costs for lost hours of work, D) Starting costs, E) Other costs[4]
	Portion of costs related to space and water heating, cooling and freezing, production processes, electric boiler, data processing etc.
	Modification of costs in case of advance warning, necessary warning time
III	CHANGES IN COSTS FROM REFERENCE TIME
	By Season (months), time of week (weekdays), time of day

IV	COST REDUCTION ACTIONS
	Type of action: Reserve supply, UPS, protection, insurance, etc
	Cost of action and valuation of reserve supply possibilities (WTP)
V	CONSUMER FLEXIBILITY
	Willingness to accept compensation in case of load shedding
	Willingness to pay for reserve supply for parts of the electricity demand

1) SIC = Standard Industrial Classification

2) 8 NOK ≈ 1 Euro

3) For large processing industry: Costs of interruptions of 1 sec., 3 min., etc. and more detailed questions about voltage disturbances

4) For public, residential and agricultural sectors: Consequences of interruptions and voltage dips for heating, cocking, washing, data communication, lighting, ventilation, elevators, safety and security, etc. Costs indicated in check boxes. Willingness to pay for reserve supply.

Table 11: Content of the questionnaire for the Norwegian survey conducted 2001-2002 [3]

Sample selection:
About 7000 respondents were randomly sampled based on Standard Industrial Classification (NACE-codes). Table 12 presents the allocation of samples for the various customer groups.

Customer group	Residential	Industry	Commercial	Agriculture	Public	Large Industry
Sample size	1000	2400	1800	800	800	220
Repeal	56	141	122	53	31	44
Real Sample	944	2259	1678	747	769	176
Response rate	45 %	27%	25 %	43 %	45 %	45 %
Incentive (lottery ticket)	40 NOK			40 NOK		

Table 12: Sample size and response rata for the Norwegian survey conducted "2001-2002"

As shown in Table 12, there was a response rate of 25 % - 45 % depending on the group, meaning that more than half of the mailed questionnaires were not returned. In addition, some of the questions of those questionnaires received were not replied to at all or not answered properly. The total number of responses included in the cost estimates is therefore reduced compared to the total number of survey responses and varies within each group for the different interruption scenarios. This is partly due to lack of data and partly due to censoring.

Cost evolution:

Comparing the surveys conducted in 1990-1991 and 2001-2001, it is found that the survey results of time dependency were rather similar. In order to make a real comparison of the development in the level of interruption costs from 1991-2001, the costs estimated from 1990-1991 survey was updated to 2002 cost levels to account for an inflation of nearly 30 % during this time period. The cost valuation methods were slightly different in the two surveys. While the survey conducted in 2001-2002 utilised a combination of DW and WTP for all groups, the results from the 1991 survey were reported as WTP for the residential group and DW for the other groups. Further, the public group was not included in the survey conducted in 1990-1991. From Table 13, we can see that the normalised costs at reference time for a 1-hour interruption found in the survey in 2001 were 12 times higher on average in the agricultural group compared to the 1991 survey. One reason for this may be a marked industrialisation within this group during the period 1991-2001. All the groups have increased their costs. From the survey 2001-2002, it was found that the time dependency in the interruption costs significant especially by weekdays and time of day [3].

Customer group	Estimate	1991[1] [NOK/kWh]	2001 [NOK/kWh]	Relative increase
Industry	DW	68.6	123.0	1.8
Commercial	DW	47.8	201.5	4.2
Large Industry	DW	19.3	23.8	1.2
Agriculture	DW	1.4	16.6	11.9
Residential	WTP	3.0	5.0	1.7
1) Updated to account for inflation				

Table 13: Comparison of survey results for Norwegian surveys conducted "1990-1991" and "2001-2002" The normalised costs refer to a 1-hour interruption. The numbers show a clear increase in the costs associated with interruptions that supersedes the general inflation [3].

Cost analysis and use of the survey results in regulation:

This part describes part of the current incentive-based regulation on continuity of supply in force from 2009. Through regulation, DSOs and the TSO are obliged to take into account customers' interruption costs symmetrically compared to other cost elements, when making decisions on investments, operation, maintenance, contingency planning, resource allocation etc. The scheme covers interruptions due to incidents at all voltage levels above 1 kV (including incidents in distribution transformers), applicable for customers connected to all voltage levels, to all DSOs and the TSO. There are no exceptions for exceptional events, but the regulated entities have the possibility to apply to NVE for exemptions. The end-users' interruption costs are calculated through a standardised system[18]. The costs for one single interruption at time *j* are calculated using the following formula (as stated in the regulation):

[18] In Norway, a standardised system for registration and reporting of faults and interruptions called FASIT is used. This system also calculates the interruption costs. It takes into account, *inter alia*, information about the network topology (NIS), customer information system (CIS), circuit breaker operations (e.g. from SCADA), load measurements and temperature data.

$$C_j = c_{ref}(r) \cdot f_{Ch} \cdot f_{Cd} \cdot f_{Cm} \cdot P_{ref} \text{ , where} \quad (1)$$

C_j = interruption cost for an interruption at time *j*
$c_{ref}(r)$ = specific interruption cost [NOK/kW] for duration r [hours] at *the reference time*
f_{Ch} = correction factor for cost (in monetary terms, NOK) for hour *h*
f_{Cd} = correction factor for cost (in monetary terms, NOK) for day *d*
f_{Cm} = correction factor for cost (in monetary terms, NOK) in month *m*
P_{ref} = interrupted power [kW] for the specific customer at the reference time

The interruption cost is calculated individually for all end-users for each single interruption they experience, and the total annual interruption costs are included in the revenue cap formula. Based on the results from the survey conducted in 2001-2002, (simplified) cost-functions have been established for each of the six customer groups included in the survey. The specific interruption costs are based on interrupted power as the normalisation factor and given as a function of the duration of each single interruption.

Customer group	Specific interruption cost [NOK/kW] for duration r [hours] at the reference time	
	All durations (r)	
Agriculture	10.6 · r + 4	
Residential	8.8 · r + 1	
	r = 0 – 4 hours	**r > 4 hours**
Industry	55.6 · r + 17	18.4 · r + 166
Commercial	97.5 · r + 20	33.1 · r + 280
Public	14.6 · r + 1	4.1 · r + 44
Large Industry	7.7 · r + 6	3.1 · r + 23

Table 14: Cost functions in the Norwegian incentive-based regulation on continuity of supply
Based on the survey conducted in “2001-2002”. Cost level is 2006, the values are adjusted for inflation (consume price index) annually

The reference time for each customer group is given in Table 15. The above-mentioned P_{ref} is calculated annually at the reference time for each end-user through the standardised system, FASIT. 11 different standardised load profiles have been established for different customer categories to be used for end-users connected to 22 kV or below. The DSOs and the TSO are obliged to have in place individual load profiles for end-users connected at 33 kV or above. Standardised load profiles have been developed through research projects, while individual load profiles shall be based upon hourly-metered values of energy supplied over a period of more than 1 year. The calculation also uses the amount of energy supplied during the previous year to correctly adjust the standardised or individual load profile for a given year, and also takes into account measured temperature data on the time of the interruption.[19]

[19] When calculation $P_{ref,}$ primarily the daily mean temperature in January at the relevant geographical location shall be used to correlate the value. If a 30 year temperature series is not available, a shorter series may be used, but under no circumstances less than 5 years. The FASIT programme will provide an error message if the temperature series is missing when calculating P_{ref}.

Agriculture	Residential	Industry	Commercial	Public	Large Industry
Thursday, January, 6am	Working day, January, 4pm	Thursday, January, 10am	Thursday, January, 10am	Working day January, 10am	Thursday, January, 10am

Table 15: Reference time for each customer group in the Norwegian incentive-based regulation on continuity of supply

The correction factors (f_{Ch}, f_{Cd} and f_{Cm}) are given in the regulation. The values are based on survey results about time dependency. The correction factor for occurrence during the day, $f_{Cd,}$ is allocated for 00h00-06h00: 06h-08h, 08h-12h, 12h-16h, 16h-20h, 20h-24h. The correction factor for occurrence during the week, f_{Cd} is allocated for “Monday-Friday”, “Saturday” and “Sunday/holidays”. The correction factor for occurrence during the year, f_{Cm} is allocated for each calendar month. If the duration of one interruption is affected by several correction factors, a weighted average of the correction factors shall apply, e.g. an interruption lasting one hour in March and one hour in April, means 50/50 weight of the correction factors for March and April, respectively. Further, if the interruption is notified in advance[20], the interruption costs (calculated first as a non-notified interruption) shall be multiplied with the following factors: agriculture (0.8); residential (0.9); industry (0.8); commercial (0.7); public (0.7); and large industry (0.9). In order to create such correction factors or to take into account the elements covered by the correction factors, this information needs to be collected through the survey, and taken into account when designing the questionnaire, seeTable 11.

The cost-functions given above relate to 2006 cost-level. For each company (i.e. for each DSO and for the TSO), NVE annually adjusts the interruption costs based on the consumer price index (CPI). Further, if a series of interruptions occurs during the same event (incident), the interruption cost shall be calculated as the sum of all durations limited to the cost of one continuous interruption[21]. Temporarily demanded reduction in the allowed load for customers connected at 33 kV or above is also included in the incentive based scheme, and costs are calculated based on the demanded reduction in load.

[20] In the questionnaire for the survey conducted in 2001-2002; the question about the effect on advance warning related to 24 hours notice in advance.

[21] This does however not affect the interruption data to be reported.

3.3 Voltage quality

3.3.1 Italy

Background information:
AEEG (Autorità per l'energia elettrica e il gas) commissioned a customer survey on two types of voltage disturbances (transient interruptions and voltage dips) during 2006-2007. Although this study cannot be considered a nationwide survey (reasons will be explained later), it also investigated the nationwide costs due to these "micro-interruptions". Further information on the survey can be found in [2] and in [9]. The results of that survey are contributing to the AEEG activities and consultation process regarding voltage quality issues.

Definition of objectives:
The approach used by AEEG for quality of supply regulation requires, before defining a regulatory framework for voltage quality issues: i) to acquire reliable measures on voltage disturbances; and ii) to assess the magnitude and weight on the national economy of voltage customer costs due to poor voltage quality. The study had the main objective of pursuing this second objective, while a MV voltage quality monitoring scheme is running since 2006 in order to pursue the first objective.

Specification of customer groups, sample selection and deployment of measurement instruments:
The study focused on industrial users. The precondition for an industrial user to be included in the study was the availability of a power quality recorder at the user's MV busbar. This condition was essential to correctly attribute costs to the voltage events of interest (micro-interruptions) and not to other phenomena. At the same time, this condition limited the number of potential respondents. In practice, the respondents belong to the group of MV end-users included in the MV Italian voltage quality monitoring: 73 points. Further, some of these are non-industrial sites. Therefore, it was decided to conduct the analysis for 50 customer sites / companies.

Consequently, the observed sample is not stratified on the Italian economy. This does not significantly affect the results of the analysis in terms of plant-level cost indicators; however, it posed some methodological problems in the projection to the national economy. Sub-sampling referred to NACE codes.

Choice of conduction method and survey conduction:
Both case-based and survey-based methods were adopted: a full testing of questionnaire, logging of events and analysis of logging journals and measurement data was performed, initially for 10 customer sites. The case-based analysis was then used for other 11 sites. A simplified survey-based methodology (telephone interview) was applied for the remaining 29 customer sites.

Check for available data:
The estimation of national annual direct costs related to micro-interruptions was obtained from the projection of plant-level cost indicators to the Italian economy. The number of employees in each industrial sector was used as main factor for extending results for each sub-sample (industrial category) to the whole national economy.

This analysis concluded that direct costs sustained only by the Observed Sensitive Sectors resulted to be in the range 252.1 - 296.3 M€/year (median value: 267,8 M€/year) and that the directs costs sustained by Unobserved Sensitive Sectors were estimated to be 315.6 M€/year (this being more uncertain, as only based on experts' valuation and not on measurements).The study also found that indirect costs due to Italian investments in protection equipment are significant as well (196.8 M€/year, all values expressed in money of year 2006).

3.3.2 Norway

Background information:
The most recent nationwide cost-estimation study (customer survey) in Norway on costs due to voltage disturbances was a joint survey including costs on electricity interruptions and voltage disturbances. The survey was conducted during 2001-2002. Customer costs evolve with time, as do estimation techniques and the results on costs due to voltage disturbances are uncertain. Therefore, in 2008 a new pre-study was performed. The pre-study was finances by NVE (Norwegian Water Resources and Energy Directorate), solely. Based on the results from that pre-study, a new nationwide cost-estimation study is now underway, including costs due to electricity interruptions, voltage disturbances and rationing, planned to be finalised during 2012. Below, examples will be described with reference to the survey from 2001-2002. Further information on the survey can be found in [3]. The project description for the current cost-estimation study is included in Annex 3.

The Norwegian quality of supply regulation contains both incentive-based regulations and specific requirements; part of the incentive-based regulation is described in section 3.2.3. NVE introduced specific limits for voltage disturbances 1 January 2005 (extended from 2006 and 2007), including voltage frequency, supply voltage variations, voltage dips and swells, rapid voltage changes, flicker severity, voltage unbalance and harmonic voltages[22]. The main purpose of the Norwegian quality of supply regulation (Reg. No. 1557 of 30 November 2004) is "(…) to contribute to ensure a satisfactory quality of supply in the Norwegian power system and a social rational operation, expansion and development of the power system. This includes taking into account public and private interests affected." One of NVE's aims in making this regulation was to uphold today's quality and not to cause a general increase in the quality of supply. Former surveys on voltage quality levels and customers' costs due to voltage disturbances (together with other research projects) have been important inputs prior to and during the development of these regulations.

Survey details:
The survey conducted in 2001-2002 is described in section 3.2.3 regarding: *Definition of objectives; Choice of consultants Specification of customer groups; Choice of cost-estimation and conduction method; Choice of normalisation factor and clarification of data needs; Design and test of questionnaires and scenarios; and Sample selection.*

[22] More details, including information about the limits, are available in English in [2].

Cost analysis:
Regarding voltage disturbances, the survey conducted in 2001-2002 was limited to voltage dips with 50 % residual voltage with 1 second duration for the same customer groups as for interruptions (as described in 3.2.3.), except for the residential group. The survey results are presented in Table 16.

Customer group	N	Normalised cost [NOK/kW]	Standard deviation [NOK/kW]
Industry	123	30.4	47.1
Commercial	128	22.1	50.5
Agricultural	83	13.6	38.9
Residential	-	-	-
Public	86	1.6	6.8
Large Industry	13	5.6	8.5

Table 16: NORWAY, survey (2001-2002) results: Normalised costs (direct worth estimate) on voltage dips (50 % residual voltage, 1 second duration), cost level 2002 [3].
N= the number of respondents included in the cost-estimation

Norwegian customer costs due to voltage dips have been estimated to be of the order of 120-440 MNOK annually.

Further, the processing industry, which is part of the customer group of large industry, was asked questions about various depths and durations of voltage dips, transient overvoltages and supply voltage variations. However, due to the low number of respondents and the uncertainty in the data, they are not presented here.

There are many uncertainties with the total cost data on voltage. Still, the estimated high costs indicate that a regulatory focus on voltage dips could be important. An ongoing cost-estimation study in Norway aims at producing more reliable data on costs due to voltage dips and other voltage disturbances as well. New and more reliable results would indeed be important for the regulator; new results are expected during 2012.

4 Conclusions

CEER has (with the support of a consultancy report [3]) prepared these recommendation on cost-estimation studies on customer and society costs due to electricity interruptions and voltage disturbances. The SINTEF consultancy report includes a comprehensive overview of various cost-estimation methods and the scientific reasoning behind, description of all necessary steps during a cost-estimation study and related recommendations for the choices to be taken, and also points out the elements that need further consideration according to country-specific characteristics. This report sets out the CEER recommendations on the above issues, drawing from the work undertaken by SINTEF.

Further, CEER draws the following conclusions from its work on this issue:

C-1: Results from cost-estimation studies on customer costs due to electricity interruptions are of key importance in order to be able to set proper incentives[23] for continuity of supply.

C-2: Results from cost-estimation studies on customer costs due to voltage disturbances are important input[24] on the consequences of various voltage disturbances when deciding where to focus regulation.

C-3: Society costs should be considered in addition to customer costs when doing a cost-estimation study, as these can differ significantly.

C-4: National Regulatory Authorities should perform nationwide cost-estimation studies regarding electricity interruptions and voltage disturbances.

C-5: A pre-study should be performed in advance of a main study in order to define the objectives and to clarify country-specific characteristics, budget and consultancy needs, possible funding partners, timeline and possibilities in general for the main study.

C-6: These GGP – including the SINTEF consultancy report – should be used as a reference when performing a nationwide cost-estimation study, always taking into account country-specific issues and needs.

C-7 – Results and experiences from cost-estimation studies shall be disseminated among interested stakeholders.

The conclusions drawn from this experience will be important for NRAs when considering regulatory developments, as a result of the implementation of the 3rd Package provisions.

[23] Including load shedding, contingency planning, preventive maintenance, softened N-1 criterion, ordinary (income) incentive based schemes, payment schemes.

[24] A cost-estimation study is not a prerequisite for introducing regulatory requirements on voltage quality; in particular requirements for continuous phenomena can be introduced without a cost-estimation study performed in advance, see also ERGEG's papers on "Towards Voltage Quality Regulation in Europe"; E06-EQS-09-03 and E07-EQS-15-03.

Annex 1 – CEER

The Council of European Energy Regulators (CEER) is a non-for-profit association in which Europe's independent national regulators of electricity and gas voluntarily cooperate to protect consumers' interests and to facilitate the creation of a single, competitive, efficient and sustainable internal market for gas and electricity in Europe. CEER has 29 members - the energy regulators from the 27 EU-Member States plus Iceland and Norway.

CEER acts as a preparatory body for the European Regulators' Group for Electricity and Gas (ERGEG). ERGEG is the European Commission's formal advisory group of energy regulators. ERGEG was established by the European Commission, in November 2003, to assist the Commission in creating a single-EU market for electricity and gas. ERGEG's members are the heads of the national energy regulatory authorities in the 27 EU Member States.

This report was prepared by the Electricity Quality of Supply Task Force of the Electricity Working Group.

Annex 2 – List of abbreviations

Term	Definition
CEER	Council of European Energy Regulators
ERGEG	European Regulators Group for Electricity and Gas
EQS TF	Electricity Quality of Supply Task Force
NRA	National Regulatory Authority
AEEG	Autorità per l'Energia Elettrica e il Gas
CAIDI	Customer Average Interruption Duration Index
CENS	Cost of Energy Not Supplied
CIS	Customer Information System
CPI	Consumer Price Index
DC	Direct Current
DSO	Distribution system operator
DW	Direct Worth
EMC	Electromagnetic Compatibility
ENS	Energy Not Supplied
FASIT	Norwegian standardised system for registration and reporting of faults and interruptions
GGP	Guidelines of Good Practice
HV	High Voltage
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MV	Medium Voltage
NACE	Classification (codes) of economic activities in the European community
NIS	Network Information System
NOU	Number of Interruptions for high voltage network Users
NVE	Norwegian Water Resources and Energy Directorate
SAIFI	System Average Interruption Freqency Index
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory Control and Data Acquisition
SIC	Standard Industrial Classification
SME	Small and Medium-sized Enterprise
TSO	Transmission system operator
UPS	Uninteruptible Power Supply
VOLL	Value of Lost Load
WTA	Willingness to pay
WTP	Willingness to accept

Table 17: List of abbreviations in the report

Annex 3 – Relevant information on past studies (e.g. project descriptions)

This annex contains summaries of practical work previously done or currently underway on surveys on costs due to electricity interruptions and voltage disturbances in several European countries, including the scope of the CEER consultancy study which was prepared as support for the present GGP.

1. *List of literature papers used as background for the consultancy report prepared by SINTEF Energy Research [3] and their availability.*
2. *CEER Consultancy study 2010 [3] terms of reference: section 2 on Scope.*
3. *Swedish cost-estimation study regarding electricity interruptions; 2003-2005*
4. *Norwegian cost-estimation study regarding electricity interruptions, voltage disturbances and rationing; 2009-2012; project description*

3.1 List of literature papers used as background for the consultancy report [3] prepared by SINTEF Energy Research and their availability.

Publication	Availability	Link	Summary in the Norwegian State of the Art report (Bowitz, E.; Hofmann, M.; Samdal, K.; Seem, C. (2010): Assessing socio-economic costs of quality problems in electricity supply - an overview of literature)
Accent (2008): *Expectations of DNOs & willingness to pay for improvements in service*. Accent, London 2008.	**OPEN ACCESS**	http://www.ofgem.gov.uk/NETWORKS/ELECDIST/QUALOFSERV/Documents1/1704rep03.pdf	Yes
Adamowicz, Wiktor; Deshazo, J. R. (2006): "Frontiers in stated preferences methods: An introduction." *Environmental and Resource Economics*, 34, 1–6, 2006.	**SpringerLink**		Yes
Adenikinju, Adeola F. (2003): "Electric infrastructure failures in Nigeria: a survey-based analysis of the costs and adjustment responses." *Energy Policy, 31*, 1519–1530, 2003.	**ScienceDirect**		Yes
Alvehag, Karin; Söder, Lennart (2007): *An Activity-based Interruption Cost Model for House-holds to be Used in Cost-Benefit Analysis*. Royal Institute of Technology, Stockholm 2007.	**OPEN ACCESS**	http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.62.5388	Yes
Anderson, Christopher W.; Santos, Joost R.; Haimes, Yacov Y. (2007): "A Risk-based Input-Output Methodology for Measuring the Effects of the August 2003 Northeast Blackout." *Economic Systems Research*,	**EBSCO**		Yes
*Baarsma, Barbara E.; Berkhout, Peter B.; Hop, J. Peter (2005): *Valuation of the Quality of the Electricity Grid - Power outages have a price too*. SEO Economic Research University of Amsterdam, 2005.	**OPEN ACCESS**	http://www.seo.nl/en/publications/discussionpapers/2005/dp41.html	No
Baarsma, Barbara E.; Hop, J. Peter (2009): "Pricing power outages in the Netherlands." *Energy*, 34, 2009.	**ScienceDirect**		Yes
Beenstock, Michael; Goldin, Ephraim; Haitovsky, Yoel (1998): "Response bias in a conjoint analysis of power outages." *Energy Economics*, 20, 135–156, 1998.	**ScienceDirect**		Yes
Bertazzi, A.; Fumugalli, E.; Schiavo, Luca Lo (2005): *The use of customer outage cost surveys in policy decision-making: the Italian experience in regulating quality of electricity supply*. CIRED 2005, IEE Conference	**IEEExplore**		Yes
*Billinton, R.; Wacker, G.; Wojczynski, E. (1982): *Customer damage resulting from electric service interruptions. Volume One – Report*. University of Saskatchewan, 1982.			No
Billinton, R. (2001): "Methods to consider customer interruption costs in power system analysis. Conseil International des Grands Réseaux Électriques (CIGRE)," *Brochures thématiques* / CIGRE Paris 2001.	**e-CIGRE**		Yes
Blass, Asher A.; Lach, Saul; Manski, Charles F. (2008): *Using elicited choice probabilties to estimate random utility models: Preferences for electricity reliability*. National Bureau of Economic Research, NBER Working	**OPEN ACCESS**	http://www.nber.org/papers/w14451.pdf	Yes
Bose, Ranjan Kumar; Shukla, Megha; Srivastava, Leena; Yaron, Gil (2006): "Cost of unserved power in Karnataka, India." *Energy Policy*, 34, 1434–1447, 2006.	**ScienceDirect**		Yes

Carlsson, Fredrik; Martinsson, Peter (2004): *Willingness to pay among Swedish households to avoid power outages - A random Parameter Tobit Model Approach. Gøteborgs Universitet*, Working paper in Economics	OPEN ACCESS	http://ideas.repec.org/p/hhs/gunwpe/0154.html	Yes
Carlsson, Fredrik; Martinsson, Peter (2008a): "Does it matter when a power outage occurs? - A choice experiment study on the willingness to pay to avoid power out-ages." *Energy Economics*, 30, 1232–1245, 2008.	ScienceDirect		Yes
Carlsson, Fredrik; Martinsson, Peter (2008b): "How Much is Too Much? - An Investigation of the Effect of the Number of Choice Sets, Context Dependence and the Choice of Bid Vectors in Choice Experiments."	SpringerLink		Yes
*Carson, R. T., N. Flores and N. F. Meade (2001): "Contingent Valuation: Controversies and Evidence." *Environmental and Resource Economics* 19, 173-210.	SpringerLink		No
Caves, Douglas W.; Herriges, Joseph A.; Windle, Robert J. (1990): "Customer demand for service reliability in the electric power industry: A synthesis of the outage cost literature." *Bulletin of Economic Research*, 42 (2),	Wiley		Yes
Concept Economics (2008): *Investigation of the value of unserved energy*. Concept Economics, 2008.	OPEN ACCESS	http://www.electricitycommission.govt.nz/pdfs/opdev/transmis/pdfsgeneral/Value-of-use-final-report.pdf	Yes
Costantini, Valeria; Gracceva, Francesco (2004): *Social costs of energy disruptions*. 2004.	OPEN ACCESS	http://ideas.repec.org/p/fem/femwpa/2004.116.html	Yes
CRA International (2008): *Assessment of the Value of Customer Reliability*. CRA International, 2008.	OPEN ACCESS	http://www.aemo.com.au/planning/0409-0002.pdf	Yes
de Nooij, Michiel; Koopmans, Carl; Carlijn, Bijvoet (2007): "The value of supply security - The costs of power interruptions: Economic input for damage reduction and investment in networks." *Energy Economics*, 29,	ScienceDirect		Yes
de Nooij, Michiel; Lieshout, Rogier; Koopmans, Carl (2009): "Optimal blackouts: Empirical results on reducing the social cost of electricity outages through efficient regional rationing." *Energy Economics*, 31, 342–347,	ScienceDirect		Yes
ECON (2008): *Kostnader ved sviktende leveringskvalitet på elektrisitet – Forprosjekt* (Costs of low quality of electricity supply, a feasibility study). Report 2008-072 from Econ Pöyry. In collaboration with TrollPower. In			Yes
EPPO (Energy Policy and Planning Office): *Energy Research Institute Chulalongkorn University (2001): Electricity outage cost study - Executive summary*. Energy Policy and Planning Office; Energy Research Institute Chulalongkorn University, 2001.	OPEN ACCESS	http://www.eppo.go.th/power/ERI-study-E/ERI-ExeSummary-E.html	Yes
Eto, Joseph H.; Koomey, Jonathan; Lehman, Bryan; Martin, Nathan; Mills, Evan; Webber, Carrie; Worrell, Ernst (2001): *Scoping Study on Trends in the Economic Value of Electricity Reliability to the U.S. Economy*. 2001.	OPEN ACCESS	http://www.escholarship.org/uc/item/140887r1	Yes
Frost, Christina; Barck-Holst, Svante; Ånäs, Per; Andersen, Anna-Lena Lövkvist (2004): *Acceptabla elavbrott? - Fyra strategier för säker elförsörjning*. Totalförsvarets forskningsinstitut, 2004.	OPEN ACCESS	http://www.energimyndigheten.se/Global/Om%20oss/Tryg%20energif%C3%B6rs%C3%B6rjning/7_bil6.pdf	Yes
*Greene, W. H. (2008): *Econometric Analysis*. Sixth Edition. Upper Saddle River, New Jersey: Prentice-Hall.	BOOK	http://www.amazon.com/Econometric-Analysis-William-H-Greene/dp/0135132452	No
*Henscher, D. A., J. M. Rose and W. H. Greene (2005): *Applied Choice Analysis: A primer.* Cambridge UK.	BOOK	http://www.amazon.com/Applied-Choice-Analysis-David-Hensher/dp/0521605776/ref=sr_1_1?ie=UTF8&s=books&qid=1277463341&sr=1-1#noop	No
Hradilek, Zdenek; Prokop, Lukas (2007): "Practical Application of Estimation of Energy not Supply." *EnergySpectrum*, 1 (2), 53–58, 2007.	EnergySpectrum		Yes

Input AS (2005): *Kartlegging av sluttbrukeres avsavnsverdier ved eventuell kraft-rasjonering i det norske kraftsystemet*. Input AS, 2005.			Yes
Kateregga, Eseza (2009): "The welfare costs of electricity outages: A contingent valuation analysis of households in the suburbs of Kampala, Jinja and Entebbe." *Journal of Development and Agricultural Economics*, 1 (1), 1–11, 2009.	**OPEN ACCESS**	http://www.academicjournals.org/JDAE/PDF/Pdf2009/Apr/Kateregga.pdf	Yes
Kivikko, K.; Mäkinen, A.; Järventausta, P.; Silvast, A.; Heine, P.; Lehtonen, M. (2008): "Comparison of reliability worth analysis methods: data anlysis and elimination methods." *IET Generation, Transmission & Distribution*, 2	**IEEExplore**		Yes
Kjølle, Gerd H.; Samdal, Knut; Singh, Balbir; Kvitastein, Olav A. (2008): "Customer Costs Related to Interruptions and Voltage Problems: Methodology and Results." *IEEE Transactions on power systems*, 23 (3),	**IEEExplore**		Yes
LaCommare, Kristina Hamachi; Eto, Joseph H. (2004): *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers*. Ernest Orlando Lawrence Berkeley National Laboratory, 2004.	**OPEN ACCESS**	http://certs.lbl.gov/pdf/55718.pdf	Yes
LaCommare, Kristina Hamachi; Eto, Joseph H. (2006): *Cost of Power Interruptions to Electricity Consumers in the United States (U.S.)*. Ernest Orlando Lawrence Berkeley National Laboratory, 2006.	**OPEN ACCESS**	http://eetd.lbl.gov/ea/ems/reports/58164.pdf	Yes
Lawton, Leora; Sullivan, Michael J.; Van Liere, Kent; Katz, Aaron (2003): *A Framework and Review of Customer Outage Costs: Integration and Analysis of Electric Utility Outage Cost Surveys*. Ernest Orlando Lawrence Berkeley National Laboratory, 2003.	**OPEN ACCESS**	http://escholarship.org/uc/item/8m2214vn	Yes
Layton, David; Moeltner, Klaus (2005): "The Cost of Power Outages to Heterogeneous Households - An Application of the Mixed Gamma-Lognormal Distribution." *Applications of Simulation Methods in Environmental and Resource Economics*, 35–54, 2005.	**BOOK**	http://books.google.com/books?id=ZmiyJlbCYwcC&dq=Applications+of+Simulation+Methods+in+Environmental+and+Resource+Economics&printsec=frontcover&source=bn&hl=no&ei=flskTPfUDqOXOOr_kKcC&sa=X&oi=book_result&ct=result&resnum=4&ved=0CDEQ6AEwAw#v=onepage&q&f=fa	Yes
Mili, L.; Krimgold, F.; Alwang, J.; Bigger, J. E. (2004): "Integrating engineering, economic, and social modeling in risks of cascading failures across interdependent complex networks." *In: International Conference on*	**IEEExplore**		Yes
Moeltner, Klaus; Layton, David (2002): "A Censored Random Coefficients Model for Pooled Survey Data with Application to the Estimation of Power Outage Costs." *The Review of Economics and Statistics*, 84 (3),	**EBSCO**		Yes
Moore, James E.; Little, Richard G.; Cho, Sungbin; Lee, Shin (2006): "Using Regional Economic Models to Estimate the Costs of Infrastructure Failures - The Cost of a Limited Interruption in Electric Power in the Los	**SAGE**		Yes
Morrison, Mark; Nalder, Craig (2009): "Willingness to Pay for Improved Quality of Electricity Supply Across Business Type and Location." *The Energy Journal*, 30 (2), 117–133, 2009.	**EBSCO**		Yes
Samdal, Knut; Kjølle, Gerd H.; Singh, Balbir; Kvitastein, Olav A. (2006): "Interruption Costs and Consumer Valuation of Reliability of Service in a Liberalised Power Market." KTH, Stockholm, Sweden – June 11-15,	**IEEExplore**		Yes
Suifeng, Wang; Qian, Ren; Yongjun, Zhang (2007): "Interruption cost evaluation for distribu-tion system reliability using analytical and statistical technique." IPEC International Power Engineering Conference;	**IEEExplore**		Yes

*Sullivan, Michael J.; Keane, D. M. (1995): *Outage cost estimation guidebook*. Electric Power Research Institute, 1995.	**BOOK**	http://www.amazon.com/Outage-cost-estimation-guidebook-Sullivan/dp/B0006QHST4/ref=sr_1_1?ie=UTF8&s=books&qid=1277463496&sr=1-1	No
Sullivan, Michael J.; Mercurio, Matthew; Schellenberg, Josh (2009): *Estimated Value of Service Reliability for Electric Utility Customers in the United States*. Ernest Orlando Lawrence Berkeley National Laboratory, 2009.	**OPEN ACCESS**	http://escholarship.org/uc/item/5hg5h4zw	Yes
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Vencorp (2009): *The value of customer reliability for the electricity transmission network - Methodology for extrapolating VCR between surveys*. Vencorp, 2009.	**OPEN ACCESS**	http://www.aemo.com.au/planning/0400-0007.pdf	Yes
Yamashita, Koji; Joo, Sung-Kwan; Li, Juan; Zhang, Pei; Liu, Chen-Ching (2008): "Analysis, control, and economic impact assessment of major blackout events." *European Transactions on Electrical Power*, 18,	**Wiley**		Yes

3.2 Extract from CEER Consultancy study 2010 [3] terms of reference: section 2 on Scope.

Scope
The consultant shall develop guidelines for how to carry out nation-wide customer surveys in various European countries related to quality of electricity supply, with the aim that these will be useful at use in single European countries. The guidelines shall include proposals for methodologies, questionnaires and checklists.

Detailed description of the task to be undertaken by the consultant
This consultancy study shall embrace the various elements of quality of electricity supply. The consultant shall evaluate existing experience at global level available through, inter alia, the literature, conference papers etc. The consultant must carry out an individual judgement and shall propose methodologies that take into account possible disadvantages in previous methods and propose new and up-to-date methods. The consultant shall point at specific areas that in particular need special attention at national level before implementing a large national survey, and highlight results from this consultancy study that can be recommended used directly without the need of country-specific adjustments. Questionnaires shall be proposed to the extent possible, as a minimum; typical examples of a number of relevant questions must be included. The guidelines shall include a proposal for content of a nation-wide survey to be carried out. Checklists regarding what needs to be done prior to and within a major nation-wide survey shall be developed to the extent possible.

The guidelines to be recommended shall embrace as a minimum but not limited to the following items separated below for continuity of supply and voltage quality.

Continuity of supply
For interruptions the guidelines shall be described in order to cover at least:

- Short and long interruptions (i.e. a variety of durations above zero).
- The effect of notifying interruptions in advance.
- How to take into account different valuation of interruptions in urban and in rural areas, in particular when comparing customers who have hardly experienced any interruptions and customers who have experienced many and long lasting interruptions. How to take into account the frequency of interruptions.
- How to do grouping of customers (e.g. residential, agricultural, public sector, industry, commercial, energy intensive and wood processing industry, critical infrastructure (e.g. cell phone communication, trains) or similar grouping). The consultant shall propose examples of suitable groupings of customers.
- How to take into account that electricity is valuated differently by different customer categories (see grouping in bullet point above).
- Pros and cons of various methods and approaches for revealing costs; e.g. stated preference methods including contingent valuation (direct costs/worth, willingness to pay, willingness to accept), conjoint analysis/choice experiments and real options, revealed preferences, use of expert or focus groups and other relevant methods.
    - How to avoid extreme answers such as zero for willingness to pay or very high and unrealistic numbers for direct costs, and how to reveal when extreme answers actually are correct.
    - Accountability of different survey methods, how it can be measured or estimated.
    - The most important uncertainties with the methods, and how they can be minimised.

  - How to avoid strategic answers.
  - Methods for triangulation.
- How to study the different effects various interruptions may have on the society as a whole, i.e. how to study the difference between the customers' interruption costs and the society's costs related to the same interruptions.
- The usefulness, i.e. pros and cons, for using postal surveys, face-to-face interviews, telephone interviews, internet surveys, expert or focus groups, taking also into account the need of and methods to ensure that the correct people within the company or household are replying to the survey.
- How to find the various points in time and other factors for worst-case scenarios that exist among European countries and how to use them.
- How the costs vary with the duration and the exact time of occurrence (hour, day, month).
- How to expand (e.g. extra-polite) data on costs due to interruptions in order to produce numbers at national level. Distinction between costs per customer, aggregated costs at national or regional level, and total costs for the society.
- Normalisation of cost data.
- Questions for a future questionnaire to the extent possible. The possible number and content of scenarios useful to include.
- Envisaged sample size and return rate.
- How to take into account that some customers have installed remedial actions in advance of a survey.
- Methods for interpreting and utilising results from surveys.

Voltage quality

For voltage disturbances the guidelines shall be described in order to cover at least:

- The effect of relevant voltage disturbances such as: voltage dips, voltage swells, transient overvoltages, slow supply voltage variations, voltage unbalance and voltage harmonics, taking into account their degree of seriousness.
- Grouping of customers (e.g. residential, agricultural, public sector, industry, commercial, energy intensive and wood processing industry, critical infrastructure (e.g. cell phone communication, trains) or similar grouping). The consultant shall propose examples of suitable groupings of customers.
- The different consequences within different customer categories (see grouping in bullet point above).
- The usefulness, i.e. pros and cons for using postal surveys, face-to-face interviews, telephone interviews, internet surveys, expert or focus groups, taking also into account the need of and methods to ensure that the correct people within the company or household are replying to the survey.
- How to expand (e.g. extra-polite) data on costs due to voltage disturbances in order to produce numbers at national level. Distinction between costs per customer, aggregated costs at national or regional level, and total costs for the society.
- Normalisation of cost data.
- Questions for a future questionnaire to the extent possible. The possible number and content of scenarios useful to include.
- Envisaged sample size and return rate.
- How to take into account that some customers have installed remedial actions in advance of a survey.
- Methods for interpreting and utilising results from surveys.

Expected deliverables from the consultant

The expected deliverables are the following:

- Presentation from the consultant of interim results in an internal CEER workshop. An explanatory note and the slide presentation shall be prepared by the consultant and disseminated to workshop participants in advance. The workshop will be located in Vienna or in Bonn;
- Written report;
    - a draft report shall be submitted for comments;
    - final report.
- Presentation of the final results at a CEER meeting in Brussels.

The final report shall be delivered in both Word and PDF-version, together with 10 hard copies.

3.3 Swedish cost-estimation study regarding electricity interruptions; 2003-2005

Consumers' valuation of quality of supply

Purpose
The purpose of this project, carried out by Department of Economics, University of Gothenburg, is to measure companies and private individuals valuation of electricity quality of supply. There are basically two different types of quality of supply that we will be concentrating on, long interruptions and short interruption of up to a few minutes.

Method
The first approach is based on the use of actual data. This can be done partly by studying the actual costs in the form of eg production (Serra and Fierro 1997; Tishler 1993) or actual willingness to pay in the market (Caves et al, 1992; Been Stock et al 1997). The second approach is based on the use of hypothetical willingness to pay from survey data (Moeltner and Layton 2002; Goett et al 2000).

The study
To investigate the willingness of reduced electricity interruptions of various types will thus different surveys with consumers being implemented. Because the effects of interruptions differ significantly for households and businesses, we will be designing various surveys for these groups. Furthermore, one can suspect that the various surveys should be designed for different types of industries. In the survey we will use a mail survey and will be developed with the help of focus groups and pilot studies before the main examination is conducted. For companies will the mail questionnaire be supplemented by interviews at the companies.

Whatever the design of the questionnaire, it is clear that the inquiry should focus on different types of delivery: long interruptions and short interruptions, and for the long interruptions is also the duration of interruptions of interest. Another important factor is when the interruption takes place: time of year, day of week and time of day. Another important part in the survey that collects information on background factors, such as what steps the companies themselves have taken to reduce the cost of electricity interruptions and the type of production pursued and if homework is done in the household. These background factors are not only important in explaining respondents' choices in the survey but can also provide direct information about the cost of electricity interruptions, such as so give business costs in order to avoid power cuts information on how they value the cost of electricity interruptions. An interesting aspect is to compare the estimates of the cost with the estimates from the survey, which thus can be seen as a test of the validity of the study. Finally, another important background information is the geographical, since it is desirable to calculate willingness to pay for interruption for different types of customers in different regions.

Schedule

Time	Activity	Reporting
Spring 2003	Literature review Focus Group Study The design of the questionnaire for the pilot survey	September 2003
Autumn 2003	The design of the questionnaire for the pilot	January 2004

	survey	
Spring 2004	Implementation and analysis of pilot study for the company	May 2004
Autumn 2004	Implementation of the main study	
Autumn 2004/Spring 2005	Analysis of the main study	May 2005
Autumn 2005	Monitoring	

Other

Budget in Swedish crowns

		Year 2003	**Year 2004**	**Year 2005**
Peter Martinsson	Labour costs per month	47 000	50 000	52 000
	Scope	1 mån	5 mån	5 mån
	Total	47 000	250 000	260 000
Fredrik Carlsson	Labour costs per month	47 000	50 000	52 000
	Scope	1 mån	5 mån	5 mån
	Total	47 000	250 000	260 000
Total		**94 000**	**500 000**	**520 000**

Total costs in Swedish crowns

	Year 2003	**Year 2004**	**Year 2005**
Salary	94 000	500 000	520 000
Travel	40 000	40 000	
Study	20 000	100 000	350 000
Conferences		40 000	40 000
Literature	15 000	15 000	
Proofreading		5 000	5 000
Management fees	62 530	259 000	338 550
Total	**231 530**	**959 000**	**1 253 550**

References

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Goett, A.A., K. Hudson and K.E. Train (2000) Customers' Choice Among Retail Energy Suppliers: The willingness to pay for service attributes, Energy Journal, 21, 1-28.

Moeltner, K. and D. Layton (2002) A censored random coefficient model for Pooled Survey Data with Application to the estimation of power outage costs, Review of Economics and Statistics 84, 552 - 561st

Serra, P. and G. Fierro (1997) outage costs in Chilean industry, Energy Economics 19, 417-434.

Swedish Electric Utilities Association (1994) Interruption Costs for electricity customers, Report of Swedish Electric Utilities Association.

3.4 Norwegian cost-estimation study regarding electricity interruptions, voltage disturbances and rationing; 2009-2012; project description

Below, please find the project description of an ongoing cost-estimation study in Norway. The cost-estimation study covers customer's and society's costs due to electricity interruptions, voltage disturbances and rationing. The cost-estimation study is partly financed by the Research Council of Norway (www.forskningsradet.no)[25], and further jointly by NVE, a trade organisation for, *inter alia*, DSOs, the TSO, one DSO and two large customers whereof one of them is both a large customer an partly a DSO. Still, NVE is the main financial contributor together with the Research Council.

Socio-economic costs of interruptions, voltage disturbances and rationing of electricity supply - Project description

1 Project objective

The overall objective of this project is to:

> *Obtain new knowledge about and develop better methods for assessing the socio-economic costs of interruptions, voltage disturbances and rationing of electricity, as a basis for a socially efficient development of the power distribution system and regulation of quality in electricity supply.*

Specific *intermediate goals* for the project include the following:

1. Establishment of individual cost functions for interruptions and voltage disturbances for large customers
2. Establishment of sector-specific cost functions for interruptions and voltage disturbances for households, public sector and private enterprises
3. Qualitative description and quantitative assessments of *socio-economic* costs resulting from interruptions at critically important infrastructure facilities
4. Identification of the driving forces behind changes in the costs resulting from interruptions and voltage disturbances, both for long-term trends and short-term variations
5. Rough quantification of the significance of the size of the area (both geographically and population-wise) affected by a interruption for the resulting socio-economic costs
6. Qualitative description and rough quantification of the costs of various forms of rationing

The scope of the project includes all customer groups, but we will prioritise those groups where the existing knowledge base is especially weak and/or where the socio-economic costs related to interruptions, voltage disturbances and rationing seem to be especially large.

[25] Funding for R&D can be allocated by the Research Council of Norway if applied for.

2 The knowledge and technology front

Up to now, cost estimates both in Norway and in other countries have usually been based on representative surveys directed at different customer groups, mapping costs for the individual end user. In this type of survey, respondents are asked to report their expected costs, sometimes also their willingness to pay, for different hypothetical scenarios for interruptions. This approach is called the contingent valuation method.

The advantage of surveys based on contingent valuation is that they yield cost data which can be used directly for the regulation of quality of electricity supply and the planning and operation of the power grid. The method, however, poses some important challenges which might not have been fully recognised up to now, especially the following:

- New studies[26] raise some doubts regarding respondents' ability to come up with realistic estimates of the factual costs, as "good answers" require in-depth knowledge of both the electro-technical consequences of interruptions and voltage disturbances for the processes of the individual respondent, and of the financial consequences. Contingent valuation implies that the respondent needs both to calculate the effects of complex events which he or she might never have experienced, and then to "translate" those into monetary terms. Both the professional debate about the method as such and the results of case studies[26] indicate that a general/widespread use of the method will entail significant methodological problems.
- Another problematic aspect is related to the use and interpretation of cost data. The costs reported by the respondents are the end users' own costs, which can differ from the costs for society at large (the socio-economic costs). This difference is especially pronounced in the case of interruptions affecting critical elements of the infrastructure, where the direct costs for the individual infrastructure facilities can be of an entirely different (smaller/less significant) order of magnitude than the overall costs for society of the same event, due to external consequences like the potential inaccessibility of infrastructure, public services etc.
- Data gained from surveys represents "snapshots in time" and reflect assessments made at a certain moment and for a certain level of quality of supply. The underlying drivers for the development in costs resulting from interruptions and voltage disturbances over time have only to a small degree been uncovered through analyses performed up to now. Regulation still has a continuous need for updated cost estimates. The project aims to meet this need for continuously updated cost estimates through dedicated analyses of the underlying cost drivers (such as income growth, structural changes in the business sector, development and proliferation/dissemination of technology, etc.).

[26] Econ-report 2008-072 Kostnader ved sviktende leveringskvalitet, gjennomført for NVE [The costs of unreliable power quality, commissioned by NVE – Norwegian only]. The project deals with methodological challenges in quantifying the socio-economic costs of power cuts, voltage fluctuations and rationing, and contains a number of qualitative interviews/cases.

The need for additional knowledge seems to be especially pronounced for costs of various forms of voltage disturbances, since research up to now has concentrated mainly on the effects of interruptions. In Norway, the costs related to voltage sags/dips have earlier been estimated to be of the same order of magnitude as those for short interruptions (< 3 min)[27], but these results cannot be regarded as entirely reliable; one of the reasons for this is that there are relatively few observations. Knowledge about the cost of different rationing regimes and potential limitations of delivery capacity is also insufficient. Moreover, the estimated costs of interruptions for individual sectors and the relation between different sectors' cost estimates in earlier Norwegian studies have been a subject of debate.
On this background, the project provides the possibility to carry out both an in-depth analysis of the individual respondent/end user (in a technical and financial sense), to generalise the results in a socio-economic perspective, and to establish dynamic mechanisms for updating cost estimates based on the cost drivers identified.

3 Research and development challenge

One of the overall challenges in this connection is to find a balance between the need for an in-depth assessment of the complex physical and economic mechanisms at work and the need to collect information from many respondents in order to collect data which are representative for all end users. These considerations pull in opposite directions. The situation requires extensive adaptation of methodology and data collection depending on which customer group and which types of interruptions and voltage disturbances are to be analyzed.

The most important research and development challenges are to:

- Identify and develop different methods that can supplement and to some degree replace contingent valuation where this method shows weaknesses, with a special emphasis on identifying the actual socio-economic costs and not just the costs for actors which are directly affected by interruptions, voltage disturbances and rationing.
- Analyse the costs of voltage sags/dips and other kinds of particularly important voltage disturbances
- Map relationships within the power grid between critical infrastructure components and other actors and describe the external effects of interrupted power delivery to infrastructure facilities
- Identify factors which affect the development of socio-economic costs over time
- Find the best possible way of collectively expressing the overall costs for interruptions, voltage disturbances and rationing on the basis of different methodological approaches

[27] K. Samdal, G. H. Kjølle, B. Singh, O. Kvitastein (2006); *Interruption Costs and Consumer Valuation of Reliability of Service in a Liberalised Power Market*, Presented at The 9th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Stockholm, Sweden.

4 Approach/method

Introduction

In this project, we bring together competences and methodological approaches which traditionally have operated separately. The project combines elements from the social sciences with approaches from the technological disciplines. This will provide a good methodological basis for estimating the socio-economic costs of interruptions, voltage disturbances and rationing. In addition, the project will, for all types of interruptions/voltage disturbances, broaden the existing focus on end user costs to also include socio-economic costs by correcting reported or calculated private costs for external effects. Another new aspect of the project is that it aims to identify and quantify the significance of different underlying cost drivers for the final cost, such as technological development and economic growth, using statistical analysis and other methods.

We supplement, and in some cases replace, the use of surveys/questionnaires with other methodological approaches such as case studies, in-depth interviews and focus/expert groups, plus the development of simulation models for ”typical” end users. In general, our set-up will entail that our researchers penetrate much deeper into conditions at the individual enterprises to understand the consequences of interruptions and voltage disturbances than has been done in earlier studies.

For some groups of end users, the approach will still be based on the statistical analysis of surveys directed at representative selections of end users, while for other end user groups we will try to identify enterprises that are ”typical” for the customer group in question. In these cases, we do not attempt to achieve statistical representativeness, but perform an in-depth analysis of one or some few enterprises which we, after a careful evaluation, perceive as typical for the segment of end users we are targeting. The reason for selecting the latter approach is that the “representative” approach by way of a survey in some cases does not manage to penetrate deeply enough and allow sufficient space for the complexity of the effects of interruptions etc. in the enterprise. These methodological considerations of ours have the clear support of different customers as expressed in various interviews[26].

The project naturally falls into three main parts:

- Collection of basic data
- Analyses
- Implications for regulation

Basic data

The basis for our various analyses consists of information from a literature survey, interviews/case studies and customer surveys/questionnaires.

Survey of literature/workshop

We will carry out a survey of the literature related to research within the thematic areas described in the section on R&D challenges. This will be based on specialist literature within the respective fields of technology/natural sciences and economics/social sciences. In connection with the literature survey, there will be a workshop with international participants. During this workshop, we will attempt to assemble a knowledge base comprising methods and experiences which is as comprehensive as possible before finalising the details of our research design.

Interviews/case studies

We will carry out case studies of both typical enterprises that use electricity as a critical contributing factor in industrial processes (electricity-driven processes), including enterprises within energy-intensive industries, but also enterprises within public and private services, including enterprises which can be regarded as a part of that infrastructure which is critical to the overall functioning of society.

Through interviews with technical and financial key personnel in the individual enterprises we will gain an impression of the physical and operational consequences of different types of interruptions and voltage disturbances. The interviews will be of a somewhat exploratory character, especially with regards to finding out which types of voltage disturbances have negative consequences for the enterprise. In our attempt to find out which types of voltage disturbances are of particular importance, we will use a broad-based approach which at the outset will not exclude any types of voltage disturbances or interruptions. We will also collect financial data as a basis for calculations of the private and socio-economic costs of interruptions/voltage disturbances.

Surveys

Surveys aimed at selected groups of end users will provide important basic data for the project. In general, we will try to tailor our questions to the end user group that we wish to analyse. As an example, public enterprises without any significant sales revenues are likely to require a different set of questions regarding the financial consequences of interruptions/voltage disturbances than for instance an enterprise that trades in goods. Normally, instead of asking the respondents to quote a monetary amount for the changes in the value creation of the enterprise, we will request information about the respective changes in sales, costs, extent of overtime required to catch up, etc. This type of questions will constitute the basis of further analyses. Such an approach ensures that cost estimates are based on the same assumptions for all respondents. To make sure that a high percentage of enterprises respond to the survey, the questions will generally be fairly simple. For private households, we wish to combine a country-wide representative study containing fairly simple questions with a survey directed at regions/areas which have experienced interruptions relatively recently, where the questions will be more detailed and numerous. The latter group of households will have a better basis from which to evaluate the consequences and also to give good estimates of willingness to pay (potentially also "willingness to accept") to avoid this type of interruptions. By combining the results from both studies we hope to arrive at a national estimate for the costs of interruptions and voltage disturbances. In addition, the surveys will contain information on some distinctive features of energy use and energy-consuming equipment, and socio-economic features for the respondent. This information will be utilised in some analyses for the project (including driving forces etc.).

Analyses

The case studies provide a basis for the design of numerical models of how for instance interruptions affect different revenue and cost components for the typical enterprise we analyse. We are planning to develop this type of model for every "typical enterprise" within electricity-driven processes, and most likely also for some end users within private and public services. By simulating different scenarios for interruptions/voltage disturbances we can quantify the financial loss for the enterprise in each scenario. We also need to discuss which normalisation factor to use (e.g. kWh energy not delivered or kW interrupted *(intermediate goal no. 1)*

The information from the surveys will, combined with technical assessments and standard valuation methodology, provide a basis for cost estimates for interruptions and voltage disturbances for enterprises within public and private services. For some of these end users, an approach that is mainly based on surveys will be the natural way to proceed, while for other groups an approach based on case studies will be more suitable. These analyses are directed at *intermediate goal no. 2*.

Based on the information from the case studies, we will carry out our own analyses of the consequences for third parties in cases where critical infrastructure fails because of interruptions. Again, our calculations will be based on assumptions of important consequences (for example a scenario where a interruption for the railway entails that all commuters in the area are on average two hours late for work), and the use of widely accepted principles for the valuation of time and other circumstances in socio-economic cost-benefit analyses. This analysis is specifically relevant to *intermediate goal no. 3*.

The analysis of driving forces will be based on interviews and other information from the case studies. We are also planning to carry out statistical analyses (regression analysis) to illuminate the significance of factors like income, presence of different types of equipment in the household, heating technology, etc. for the costs resulting from interruptions and voltage disturbances. This analysis is specifically relevant to *intermediate goal no. 4.*

We will also carry out our own analysis packages where we will examine the significance of the size of the affected area (both geographical and population-wise) for the resulting costs. Here we will focus on the socio-economic costs of different rationing scenarios. The basis for these analyses are the reported data from different end users regarding the different effects and costs resulting from interruptions, but these will be combined with additional assessments and analyses from our side. These analyses are directed at *intermediate goals no. 5 and 6*.

Implications for regulation

During these activities, we will sum up and compare the results from the individual analyses and assess whether the estimates for the different sectors and end user groups seem to be in reasonable proportions to each other. In addition, we will assess whether the estimates for rationing costs and the significance of the size of the affected area are in accordance with the results we found for the costs of interruptions and voltage disturbances for the different end user groups. As one element in this process of summarising our findings, we will organise a workshop with our international research partners to discuss *analysis results and use of methodology*.

In a general way, we will draft which implications our results should have for the regulation of delivery quality both in the shape of direct regulation (rules) and in the form of compensation rates for undelivered energy and/or other financial incentives. The analysis of the driving forces behind changes in costs over time also provides a basis for reflections on how cost estimates should be updated over time, including an assessment of the degree to which the results from the regression analyses can be used to update cost estimates with the help of continually aggregated data without having to collect new primary data from end users. Regression analyses will also be able to provide a basis for updating cost estimates continually as a consequence of economic growth (income/revenue growth), the trend growth rate in the number of end users owning equipment that protects them against short interruptions of the power supply (such as UPS-equipment), or changes in the trend rate for the use of different types of power-consuming equipment (such as the share of consumers using electrical heating, owning PCs and other home electronics), etc.

Finally, there will be seminar with the purpose of *disseminating the results* nation-wide and internationally.

Summary of work plan

Activity package	Activities
A1 Literature survey/ Workshop 1	
A2 Electricity-driven processes	Interviews and case studies with 8-12 representative enterprises
A3 Public activities and private services	Tailored surveys for different customer groups (5-7 segments), case studies.
A4 Households	National survey Tailored surveys aimed at areas that have experienced frequent interruptions; case studies and focus groups
A5 Driving forces for cost changes	Statistical and qualitative analysis of driving forces
A6 Critical infrastructure	Case studies, calculations
A7 Significance of the size (geographical/- population -wise) of the affected area	Analysis of the significance of the size of the area experiencing a interruption, for the resulting costs
A8 Rationing	Basic analysis of the socio-economic costs of different types of rationing schemes.
A9 Implications for regulation	Summary of findings, general regulatory possibilities
A10 Dissemination of results	Journal articles, international workshop for researchers, national seminar for stakeholders