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Study on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances

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RESULT (summary)

This report deals with cost estimation studies on electricity interruptions and voltage disturbances. It is divided in two parts; the recommended guidelines and the state of the art of methodologies.

The guidelines give a short and practical description of how to execute a complete customer cost estimation study. They summarize the proposed approaches including specifications of customer groups, choice of cost estimation method and a description of the survey based and case based approaches. The guideline for cost estimation due to interruptions is mainly based on the survey based approach. Direct worth is recommended for Households, Industry, Commercial services and Public services. In addition, Contingent valuation is recommended for Households and Public services. An alternative cost estimation method for Households is Conjoint analysis. The interruption costs of Large customers and Infrastructure should be analyzed with a case based approach. The guideline for estimating costs of voltage disturbances focuses mainly on a case based approach. Reliable data can be collected with measurements and logging of events for Industry, Large customers and Infrastructure. Other customer groups have to be analyzed with the survey based approach. The report also gives examples of questionnaires and some considerations of country specific characteristics that need special attention at national level before implementing a nationwide cost study.

The state of the art of methodologies gives an overview based on an extensive literature research regarding methodologies for revealing costs of quality of supply problems. Advantages and disadvantages of different methods, the design and conduction of questionnaires, and the analysis of the collected data are described. In addition, cost results of recent cost studies are presented.

KEYWORDS

SELECTED BY AUTHOR(S)		
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1 INTRODUCTION

This report is a result of a consultancy study performed in the period mid-June till the end of October 2010 to support the Council of European Energy Regulators (CEER) in their preparations of Guidelines for Good Practice on Estimation of Costs due to Electricity Interruptions and Voltage Disturbances as described in the terms of reference (ToR)[1]. CEER's main objective is to provide a set of recommendations on how to design and develop nationwide cost-estimation studies, to highlight the possible problems (already experienced by some countries) in order to finally improve the effectiveness of possible future studies and the quality and comparability of their results. These guidelines aim at providing improved methodologies for studies on customers' and society's costs due to interruptions and voltage disturbances in the supply of electricity as well as possible questionnaires and checklists for use in such studies.

1.1 QUALITY OF ELECTRICITY SUPPLY AND THE NEED FOR COST DATA

Quality of electricity supply can as stated in the ToR and by CEER (2001) 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 guidelines presented in this report deals only with surveys on costs related to continuity of supply and voltage quality.

While several CEER member countries have implemented financial incentives in their regulation in order to optimise the level of continuity of supply, voltage quality is still a rather new subject for many regulators. In order to find the optimal level of quality of supply from society's point of view it is important to balance the costs of providing the quality levels against the customer and society costs related to interruptions and voltage disturbances. For the purpose of providing credible and reliable quality regulation schemes it is of great importance to have sufficient knowledge about these costs.

The following list shows the most common and important types of applications of the cost data which can be directly or indirectly related to quality of supply regulation:

- Taking explicitly account of quality of supply costs in the regulation
    - Incentive based regulation, penalty schemes etc.
- Policies, standards and criteria for quality of supply
    - Guaranteed quality of supply levels, contracts, softened N-1 criterion etc.
- Monitoring quality of supply
    - Actual levels vs standards, expectations etc.
- Planning of power systems
    - Basis for concession applications, justifications of investments etc.

[1] ToR For the consultancy study "CEER Guidelines of Good Practice on Harmonised Surveys on Quality of Electricity Supply", 26th of March 2010, C10-EQS-37-03b

- Operation and maintenance
    - Cost-benefit analyses of quality of supply improving measures, priorities for load shedding, contingency planning, preventive maintenance etc.

1.2 SCOPE OF STUDY AND ORGANISATION OF THE REPORT

The scope of the consultancy study is to develop guidelines for carrying out nationwide customer cost studies in various European countries.

The report is divided in two parts: part A presenting the guidelines and part B describing state of the art of methodologies for customer cost studies on quality of supply problems. Part B forms the theoretical background and reasoning for the recommended guidelines. Part A can be read independently of Part B, if one is not interested in the scientific reasoning of why this approach has been proposed.

Practical guidelines are developed for how to perform a customer cost study related to continuity of supply and voltage disturbances respectively. The guidelines (part A) summarize the approaches proposed by SINTEF for cost studies including specifications of customer groups, choice of cost estimation and conduction method, design of questionnaires and scenarios, sample selection, choice of normalization factors and estimation of cost data. The guidelines give 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 report also gives examples of questionnaires and some considerations of country specific characteristics that need special attention at national level before implementing a nationwide cost study.

Part B of the report serves as the scientific basis for the proposed guidelines 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 experiences of the authors of this report. Methods and approaches are presented with their advantages and disadvantages. It is described how to design a questionnaire and how to conduct a customer survey including customer characteristics as well as interruptions and voltage disturbance scenarios. This part of the report deals also with the estimation of usable cost parameters from the survey data.

2 DEFINITIONS

This chapter defines the two technical elements of quality of electricity supply; continuity of supply and voltage quality. The various cost terms used in the report are defined and the customer groups are described as well as effects of quality of supply problems.

2.1 QUALITY OF ELECTRICITY SUPPLY

Quality of electricity supply can be divided into three main elements; continuity of supply, voltage quality, and commercial quality. Continuity of supply is characterised by the number and duration of interruptions while voltage quality describes the technical properties of the electricity in terms of frequency, voltage magnitude and waveform. The guidelines presented in this report deals only with studies on estimation of costs due to interruptions and voltage disturbances. If both quality of supply elements are meant the term quality of supply problem will be used.

2.1.1 Interruptions

Supply interruption is a condition in which the voltage at the supply terminals is lower than 5 % of the reference voltage (EN50160:2010).

NOTE 1 Classification: a supply interruption can be classified as:

a) prearranged, when network users are informed in advance; or
b) accidental, caused by permanent or transient faults, mostly related to external events, equipment failures or interference. An accidental interruption is classified as:
    1) a long interruption (longer than 3 min);
    2) a short interruption (up to and including 3 min).

NOTE 2 Normally, interruptions are caused by the operation of switches or protective devices.

NOTE 3 The effect of a prearranged interruption can be minimized by network users by taking appropriate measures.

NOTE 4 Prearranged interruptions are typically due to the execution of scheduled works on the electricity network.

NOTE 5 Accidental supply interruptions are unpredictable, largely random events.

NOTE 6 For polyphase systems, an interruption occurs when the voltage falls below 5 % of the reference voltage on all phases (otherwise, it is considered to be a dip).

NOTE 7 In some countries, the term Very Short Interruptions (VSI) or transitory interruptions are used to classify interruptions with duration shorter than 1 s to 5 s. Such interruptions are related to automatic reclosing device operation.

2.1.2 Voltage disturbances

The ideal voltage has a nominal r.m.s. value (e.g. 230 V r.m.s in low voltage distribution systems), a perfect sinusoidal wave shape and a constant fundamental frequency (e.g. 50 Hz). Both international standards like the EN50160, IEC 61000-2-2 etc and national regulations in some countries specify normal operation conditions for the supply voltage. The voltage may thus vary somewhat from the ideal voltage and still be considered as a normal voltage. When the voltage deviates from the specified normal voltage levels and a sinusoidal wave shape it is considered as a voltage disturbance.

Some of the voltage parameters describe the normal voltage range as a window where for example the voltage r.m.s. value should be between these values. Other voltage parameters may as an example simply describe a voltage deviation from the ideal voltage that is considered as normal voltage as long as it does not occur too often during a specified time interval.

The most commonly evaluated voltage quality parameters are:

- Frequency of the supply voltage
- Supply voltage variations
- Voltage dip
- Voltage swells
- Rapid voltage change
- Flicker
- Transient overvoltages
- Unbalance
- Harmonic voltage
- Interharmonic voltage.

Frequency of the supply voltage
The frequency of the supply voltage is the repetition rate of the fundamental wave of the supply voltage measured over a given interval of time (EN50160:2010).

Supply voltage variations
The supply voltage is the r.m.s. value of the voltage at a given time at the supply terminal, measured over a given interval. The voltage variation is the increase or decrease of r.m.s. voltage normally due to load variations (EN50160:2010). Supply voltage variations are commonly measured as 10 minutes averages (EN50160:2010) although there are exceptions like for example some national regulations.

Voltage dip
A voltage dip is a temporary reduction of the r.m.s. voltage at a point in the electrical supply system below a specified start threshold (EN50160:2010).

NOTE 1 Application: for the purpose of this standard (*EN50160:2010*), the dip start threshold is equal to 90 % of the reference voltage

NOTE 2 Typically, a dip is associated with the occurrence and termination of a short circuit or other extreme current increase on the system or installations connected to it.

NOTE 3 For the purpose of this standard (*EN50160:2010*), a voltage dip is a two dimensional electromagnetic disturbance, the level of which is determined by both voltage and time (duration).

Voltage swells

A voltage swell is a temporary power frequency overvoltage, i.e. a temporary increase of the r.m.s. voltage at a point in the electrical supply system above a specified start threshold (EN50160:2010).

NOTE 1 Application: for the purpose of this standard (EN50160:2010), the swell start threshold is equal to the 110 % of the reference voltage.

NOTE 2 For the purpose of this standard (EN50160:2010), a voltage swell is a two dimensional electromagnetic disturbance, the level of which is determined by both voltage and time (duration).

NOTE 3 Voltage swells may appear between live conductors or between live conductors and earth. Depending on the neutral arrangement, faults to ground may also give rise to overvoltages between healthy phases and neutral.

Rapid voltage change

A rapid voltage change is a single rapid variation of the r.m.s. value of a voltage between two consecutive levels which are sustained for definite but unspecified durations (EN50160:2010). The voltage levels for a rapid voltage is between the voltage dip and voltage swell start levels, else the voltage variation would be defined as a dip or a swell.

Flicker

Flicker is the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time (EN50160:2010). Voltage fluctuation is a series of voltage changes or a cyclic variation of the voltage envelope. Voltage fluctuation cause changes of the luminance of lamps which can create the visual phenomenon called flicker. Above a certain threshold flicker becomes annoying. The annoyance grows very rapidly with the amplitude of the fluctuation. At certain repetition rates even very small amplitudes can be annoying.

Flicker severity is the intensity of flicker annoyance defined by the UIE-IEC flicker measuring method and evaluated by the following quantities (EN50160:2010):

- short term severity (P_{st}) measured over a period of ten minutes;
- long term severity (P_{lt}) calculated from a sequence of twelve P_{st}-values over a two hour interval, according to the following expression:

$$P_{lt} = \sqrt[3]{\sum_{i=1}^{12} \frac{p_{sti^3}}{12}}$$

Transient overvoltages

A transient overvoltage is a short duration oscillatory or non-oscillatory overvoltage usually highly damped and with a duration of a few milliseconds or less (EN50160:2010). Transient overvoltages are usually caused by lightning, switching or operation of fuses. The rise time of a transient overvoltage can vary from less than a microsecond up to a few milliseconds.

Voltage unbalance

Condition in a polyphase system in which the r.m.s. values of the line-to-line voltages (fundamental component), or the phase angles between consecutive line voltages, are not all equal (EN50160:2010). The degree of the inequality is usually expressed as the ratios of the negative and zero sequence components to the positive sequence component.

Harmonic voltage

Harmonic voltages are sinusoidal voltages with a frequency equal to an integer multiple of the fundamental frequency of the supply voltage (EN50160:2010). Harmonic voltages can be evaluated:

- individually by their relative amplitude (u_h) which is the harmonic voltage related to the fundamental voltage u_1, where h is the order of the harmonic
- globally, for example by the total harmonic distortion factor THD, calculated using the following expression:

$$THD = \sqrt{\sum_{h=2}^{n} (u_h)^2}$$

NOTE Harmonics of the supply voltage are caused mainly by network users' non-linear loads connected to all voltage levels of the supply network. Harmonic currents flowing through the network impedance give rise to harmonic voltages. Harmonic currents and network impedances and thus the harmonic voltages at the supply terminals vary in time.

Interharmonic voltage

Interharmonic voltages are sinusoidal voltages with a frequency not equal to an integer multiple of the fundamental (EN50160:2010).

2.2 GROUPS OF CUSTOMERS AND EFFECTS OF QUALITY OF SUPPLY PROBLEMS

Interruptions and voltage disturbances have different consequences on different customers. This chapter describes how the customers can be categorized into different groups and what consequences they suffer from the quality of supply problems.

2.2.1 Categorization of customer groups and general effects of quality of supply problems

A cost estimation survey has to deal with several categories of customers who valuate electricity in a different way and experience different consequences of quality of supply problems. Each of these customer groups should be surveyed with methods adjusted to the characteristics of this specific group. The main criteria for dividing customers into several groups are:

- Consequences of quality problems
- Method to collect cost data of the consequences from the customers

If a group of customers suffers comparable consequences of a quality of supply problem and the cost of the consequences can be collected with the same method, they should be categorized in the same category. In the following different customer groups and their specific consequences due to quality supply problems will be presented.

Based on the specific characteristics of the customers, they are commonly divided into the following *basic* groups:

- Households
- Industry
- Commercial services and Public services.

Households
A household consists of the people living in a defined unit. Households can for example be a family living in their own house or students living in a dormitory or a cabin. Interruptions cause mainly non-monetary costs for Households in form of inconvenience. In case of an interruption the persons present in the building might not continue with their planned activities as watching TV, while voltage disturbances may cause damage to PC equipment.

Industry
Industry is defined as enterprises who manufacture products. The main costs in connection to an interruption or voltage disturbance are monetary costs because of lost production time and damages to products and physical equipment. The Industry sector includes also the agriculture sector even though that several surveys define agriculture as an independent group. Depending on the economic importance in a countries' economy in terms of turnover and employees or other important reasons, it can also be decided to define agriculture as an additional customer group. But it can be expected that the total cost of interruptions/voltage disturbances in agriculture is too low in most of the European countries to justify a special survey for this group, since the overall

contribution of agriculture to the whole economy is quite low[2]. Even though, it can be worthwhile for individual countries with a large agricultural sector to define agriculture as an extra customer group.

Commercial services and Public services
Commercial services and Public services deliver different kinds of services to the Households and Industry. In the case of a quality of supply problem the main costs arise from the loss of working hours, damage of equipment and spill-over costs.

The service sector and the industrial sector can also be split into small and large customers since it can be useful to estimate separate cost functions for the largest customers. Public services should be separated from the commercial businesses as a consequence that costs of quality of supply problems are difficult to estimate for them since they do not generate income. In addition all complex infrastructure systems should be defined as an extra customer group. The private cost of infrastructure systems are usually low whereas the costs for their customers are large due to loss of infrastructure services.

A more detailed grouping of the customers is as follows:

- Households
- Commercial services (without "Infrastructure")
- Public services (without "Infrastructure")
- Industry (without "Large customers")
- Large customers
- Infrastructure.

The definitions of Large customers and Infrastructure are given below.

Large customers
Large customers are characterized by a high consumption of electricity and are normally connected to the higher grid levels. They suffer high costs (in absolute terms) from interruptions and voltage disturbances compared to the average customer.

Infrastructure
Infrastructure represents key facilities in transportation, telecommunication and water and sewage systems. Interruptions have large consequences if they affect the infrastructure, mainly due to the large spill-over effects on the rest of the society. The cost assessment of the infrastructure has to be based on significant other methods than for the other customer groups, due to the complex consequences when infrastructure facilities are exposed to quality of supply problems.

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[2] The average contribution of agriculture to the gross domestic product is around 1.2 % in the EU-27 (data from Eurostat year 2008).

2.2.2 Effects of voltage disturbances

The proposed grouping of customers should be used also for voltage disturbances surveys. In the following the effects of different voltage disturbances are described.

Consequences of voltage disturbances are best described grouped according to the different types of voltage disturbances. The consequences for the different customer categories vary a lot and this variation also yields within the customer categories. The socio-economic consequences of voltage disturbances to household customers are low compared to the costs of such voltage disturbances to the other customer categories. Still, when household customers get a lot of electrical equipment (appliances) damaged due to for example transient overvoltages from a lightning strike, the costs may be very high and the consequences will be large compared to simply visual annoyance due to flicker (voltage fluctuations) or a high number of rapid voltage changes.

As an example the customer category specific consequences are summarized in Table 1 in qualitative terms from the experiences made in Norway through several voltage quality research projects (survey/questionnaire: 1993 – 2010) and a lot of troubleshooting assignments for hundreds of customers. It is important to notice that the low, medium and high consequences are weighted individually for each customer category. A voltage disturbance with high consequences for a household customer is of course worse for him/her than a disturbance with low consequences. But this will often still have less socio-economic consequences than if for example Commercial services and Industry experience the same voltage disturbance.

Table 1: Relative consequences of voltage disturbances for different customer categories in Norway (1993 – 2010)

	Households	Commercial services (without "Infrastructure")	Governmental services (without "Infrastructure")	Industry (without "Large customers")	Large customers	Infrastructure
Frequency of the supply voltage	Low	Medium	Low	High	High	Medium
Supply voltage variations	Medium	Medium/high	Medium/high	Medium/high	Medium/high	Medium/high
Voltage dip	Medium	Medium	Medium	Medium/high	Medium/high	Medium/high
Voltage swells	Medium/high	Medium/high	Medium/high	Medium/high	Medium/high	Medium/high
Rapid voltage change	Low/medium	Low/medium	Low/medium	Low/medium	Low/medium	Low
Flicker	Medium	Medium	Medium	Medium	Medium	Low/medium
Transient over-voltages	High	High	High	High	High	High
Unbalance	Low/medium	Medium	Medium	Medium/high	Medium/high	Low/medium
Harmonic voltage	Medium	Medium	Medium	Medium/high	Medium/high	Medium
Interharmonic voltage	Low	Low	Low	Low/medium	Low/medium	Low

How the customers are affected by voltage disturbances does not only vary a lot between the customer categories but also depending on the type of voltage disturbance. Experiences in several countries show that the voltage quality phenomena which seem to cause the highest costs are voltage dips, voltage swells, transient overvoltages, harmonic voltages and supply voltage variations.

Frequency of the supply voltage: In large synchronized networks the frequency variations are often very small or at least moderate. In smaller local networks (e.g. emergency generator operation or "power network islanding") larger frequency variations may occur. Large frequency variations will usually not represent high consequences for household customers or even Commercial services and Public services. Industry (in particular Large customers) and Infrastructure may experience larger consequences. This is partly due to the use of advanced and precision electrical equipment like for example large frequency controlled motor drives. Examples of problems due to large frequency variations:

- Harmonic filters change resonance frequency
- Electrical motors may get deviation in power or wrong speed
- Some watches/clocks may speed or slow and show error in time.

Supply voltage variations: Even with quite large supply voltage variations (slow variations, e.g. EN50160, 10 min average) some customers are not affected. This is typically Large customers and some industrial customers that for example have their own transformers with automatic voltage controlled tap-changing. Among most customers there are also quite many electrical appliances that are not affected by supply voltage variations as long as the deviation from nominal voltage is not very large. There are ordinary and low cost appliances that compensate for a varying voltage by varying the load current for an almost constant power consumption. Examples of problems due to (slow) supply voltage variations:

- Reduced power
- Reduced light output
- Increased losses
- Equipment overheating.
- Reduced lifetime of equipment/appliances.

Voltage dip: The consequences of voltage dips are mainly due to that electrical equipment, processes and appliances stop working properly if only for a short moment. Some equipment however also needs a manual restart after voltage dip. Even though damage to electrical equipment sometimes occur (for example in frequency controlled motor drives when high rate of voltage change during voltage recovery) such damage is not very common. The consequences of voltage dips are significant for most customers even though it might be more like annoyance than actual costs for household customers while the other customer categories can suffer economic consequences. This might quite often be large costs for some of the industrial customers and Large customers and moderate to low costs for Commercial services, Public services. Voltage dips may also have large consequences for Infrastructure.

Examples of problems due to voltage dips:

- Tripping of computers and other electrical equipment
- Tripping of street lighting and UV water treatment lamps (takes a long time to restart)
- Tripping of large complex industrial processes that may take hours or even days to start.

Voltage swells: The consequences of voltage swells are usually higher than with voltage dips for most customers since voltage swells are more likely to cause damage to electrical equipment than voltage dips. On the other hand, large/serious voltage swells usually occur more seldom than large voltage dips. There have not been documented large differences in consequences from voltage swells between the different customer categories. Examples of problems due to voltage swells:

- Damage to electrical equipment and appliances
- Tripping of large complex industrial processes that may take hours or even days to start.

Rapid voltage change: The consequences of rapid voltage changes will for most customers simply be that people get annoyed by poor lighting quality as unstable light intensity from lighting equipment. There is very limited number of electrical equipment that is sensitive (that it affects its operation in a noticeable way) to such moderate voltage changes as rapid voltage changes in the range of U_N +/- 10 %. In very weak networks where large motors or other large loads turn on and off several times per hour customers often starts to complain to the local network operator.

Flicker: As with rapid voltage changes flicker mainly have consequences in terms of poor lighting quality and seldom cause problems for the operation of electrical equipment. When lighting quality gets very poor due to flicker it will be a problem for all customers and customer installations where people depend on electrical lighting equipment to do their job or simply their usual home activities. Flicker is one of the voltage quality parameters where it is very difficult to estimate the costs of having large voltage disturbances.

Transient overvoltages: Most customers will experience large consequences from transient overvoltages when such disturbances become very large since this will lead to widespread damage to electrical equipment. The risk of equipment damage is reduced by installing overvoltage protection but even then customers may experience severe damages if their installation gets a direct hit by a lightning strike or a very nearby lightning strike. Examples of problems due to transient overvoltages:

- Damage to electrical equipment and appliances
- Tripping of electrical circuits and equipment by moderate size transients.

Unbalance: It is mostly customers with poly phase electrical equipment that might suffer from large unbalance situations. Household customers and partly Commercial services and Public services have limited number or even none poly phase electrical equipment. Industrial customers, Large customers and some Infrastructure customers often have poly phase electrical equipment like large motors and motor drives. Examples of problems due to unbalance:

- Increased currents and voltage drop
- Increased losses
- Overheating and reduced life time and load capability in three phase motors.

Harmonic voltage: Most customers might experience problems and have moderate to high consequences from large harmonic voltages. Examples of problems due to large harmonic voltages:

- Malfunction of electrical equipment including lighting control equipment
- Increased losses
- Overheating (there have been cases with fires)
- Damage to equipment.

Interharmonic voltage: Relatively little experience have been made and research done on the problems interharmonic voltages may cause for electricity customers. There is also limited knowledge on what the consequences are for the different customer categories. Interharmonic voltages are amongst others known to cause poor lighting quality if the interharmonic voltages are of unfavourable frequencies.

2.3 COST TERMS FOR DESCRIBING CONSEQUENCES

In this section we will give an explanation to the cost concepts used in this report. Total socio-economic cost is the sum of net customer costs and net costs to the rest of society (spill-over costs). Both types of costs may also be classified in direct and indirect costs, as well as in monetary (financial) and non-monetary costs. See figure below.[3]

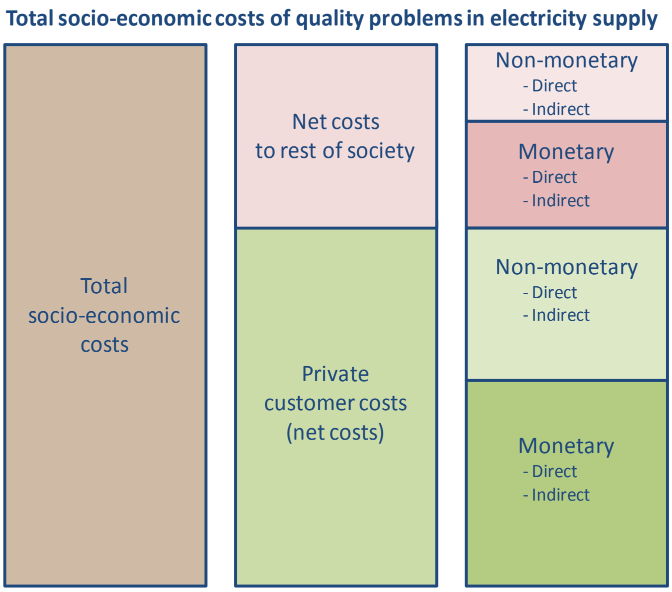

Figure 1: Categorization of different cost terms

[3] In economic literature on valuation of non-market goods it is also common to differentiate between use value and non-use value. Use values relates to actual use of the good, which could for example be a natural resource (use value include option value which is the value an individual places on future use). Non-use value refers to the willingness to pay to maintain the good in existence – even without planning to use it. In our case this distinction is less relevant, as we focus on a private good; electricity. However, it is worth noting that none-use value might in principle be relevant. For example if people have a willingness to pay for others (friends, relatives or the local community in general) avoiding quality problems in their electricity supply. Stated preference is the only method that covers non-use value.

In the following the different cost concepts will be explained in detail as well as the concept of option value.

Direct costs
Direct costs are costs which occur directly connected to a quality of supply problem (interruption or voltage disturbance) in a close time horizon. A typical example can be destroyed equipment or lost production because of an interruption.

Indirect costs
Indirect costs are costs with a longer time horizon and not such a clear connection to a single event. An example can be the decision to have a higher stock keeping or a continuous inconvenience of persons due to the uncertainty if and when the next interruption can occur.

Monetary costs
Monetary costs to customers may (at least in principle) be relatively easily measured, and some cost estimation studies focus exclusively on this cost category. Monetary costs tend to be more important for Commercial services, Public services and particularly Industry than for Households, and they will typically include:

- Lost production
- Additional overtime to recover lost production
- Damage to equipment, products and raw material
- Idle but paid-for resources (raw materials, labour, capital)
- Costs to operate back-up generation
- Re-start costs
- Costs of the alternative to production lost (buying products/services from another producer)
- Costs of penalty payment
- Direct costs associated with human health and safety.

All the above mentioned costs are direct costs, resulting directly from the interruption or voltage disturbance. In addition, the quality of supply problem may incur more indirect and long term costs: for example delayed or lost deliveries may lead to customer dissatisfaction, and thereby loss of future business. The customer may also, in the fear of future interruptions, decide to install back-up solutions or other preparatory actions.

It is important to note that these are net costs, in the sense that they need to be determined net of any savings on electricity, materials, and labour during the interruption. For example, lost production can in many cases be made up, through the use of overtime or additional shifts.

Non-monetary costs
Non-monetary costs to customers are often especially relevant for the household sector. Costs of this type include ‘annoyance’ or ‘inconvenience’ and loss of leisure time caused by interruption of activities (flickering lights, uncomfortable building temperature, not being able to cook or to watch TV etc). Time that may be spent on other valuable activities instead of what was planned,

should not be considered completely lost however. In some cases the interruption or voltage disturbance may cause fear or even personal injury, not only during the interruption but also in the form of nervousness for future problems (indirect cost).

Private customer costs
Private costs are costs incurred directly by the customer who experience the quality of supply problem. They can be monetary or non-monetary. Examples are listed under monetary and non-monetary costs. The costs are always net costs, so possible savings as for example not used raw materials have to be included.

Net costs to rest of society
By "rest of society" we mean others than the electricity customer, who are affected through their connection to the customer (e.g. being a supplier, client, producer of complementary or substitute goods etc). Monetary as well as non-monetary costs may also be incurred by other parties. An example is clients of a production facility who do not receive the intended delivery on time. This may cause spill-over effect where clients in turn lose production and are not able to serve their clients on time. Another example is the costs and inconveniences for passengers if a supply interruption disrupts the train traffic. In the latter case, the costs of the commuters might probably exceed the costs that incur to the train company.

However, spill-over costs do not always have to be negative. Other companies can for example benefit from an interruption that affects a competitor, if they can increase their sales and production. This will reduce the interruption costs for the clients/users, who then receive their delivery after all. Clients may however still have net costs in the form of inconvenience of having to go to another supplier, and not being able to choose the most preferred solution.

It may especially be relevant to assess the consequences for third parties when the customer is an owner of critical infrastructure or social/municipality services. Supply interruptions and voltage disturbances are of course particularly serious in institutions where life and health may be endangered. These customers normally have invested heavily in back-up solutions, and such costs are also to be counted as costs caused by the quality of supply problems.

Total socio-economic costs
The total socio-economic costs are the sum of all cost terms. The private net costs and the spill-over net costs result in the total costs. It is important to avoid double counting of costs, e.g. some customers can report spill-over costs to their supply chain, but these companies can also be affected directly by the same interruption and will report these costs as well as private costs.

Option value
It is worth noticing that cost estimation studies are also capable of capturing the option value of the costs (OV). The option value measures the willingness to pay of the customers for the reduction of uncertainty. In the case of quality of supply problems, the customer is uncertain about if he/she will experience a quality of supply problem in the future and what consequences it will have. The customers have therefore ex ante a willingness to pay for the possibility to know

that they will not be exposed to interruptions and voltage disturbances or that they will suffer none or minimal consequences. Measuring the costs of an interruption or a voltage disturbance directly gives an expected cost value E. A risk avert customer will however be willing to pay an option price OP = E + OV that exceeds the expected cost value. The option price can be measured by the cost of insurances or other defensive expenditure, and will then include the expected costs of the quality of supply problem as well as the option value for reducing the uncertainty.

PART A

GUIDELINES FOR CUSTOMER SURVEYS ON COSTS DUE TO INTERRUPTIONS AND VOLTAGE DISTURBANCES

The guidelines and recommendations for customer surveys on costs due to electricity interruptions and voltage disturbances are developed based on the state of the art of survey methodologies presented in part B. The recommendations in the guidelines are given by SINTEF. These recommendations should be seen in the context of customer surveys (questionnaires) and case based studies with regard to various concerns such as practicalities, resources for conducting studies and other. These recommendations may deviate in some cases from suggestions of the state of the art based on literature and theory as presented in part B. Our general advices should furthermore be adjusted to country specific requirements.

The guidelines describe the approach for a complete study. But often, it is useful to perform a prestudy before conducting a complete study. Such a prestudy could help to identify expected costs of different customer groups, based on a mapping of possible consequence. It can deliver valuable information of which customers the study should be focused on and which aspects to include. In addition, the experiences of the prestudy could help to estimate more reliably the resource and budget needs for the complete study.

The cost estimation studies for interruptions and voltage disturbances can be carried out in one joint study or in two separate studies. Both approaches have their advantages and disadvantages. A joint study is first of all more cost effective since it can utilize synergy effects. A main cost saving can be achieved by designing questionnaires so that they include questions about interruptions and voltage disturbances. Secondly, it can be assured to get cost results which are comparable, since it is easier to have control about the applied methods in a joint study than in separate ones. Thirdly, the cost estimates can be collected in a small time window, which is important because cost estimates are changing over larger time horizons. Causes for changes in cost estimates are for example changes in the use of electricity or changes in the respondents' judgement of quality of supply due to the experience of a blackout or general changes in the society. Similar reasoning related to synergies, comparable cost estimates and costs changing over time can be made regarding a joint survey for all customer groups versus separate surveys for groups of customers.

Separate studies have the advantage that experiences done in the first study can be incorporated into the next study. In addition, yearly budgets can be quite limited and not sufficient to perform a joint study. In that case, it can be worthwhile to carry out separate studies one by one with smaller budget for each study instead of one large budget for a joint study of interruptions and voltage disturbances or for all customer groups. The advantages and disadvantages can be summarized as in Table 2.

Table 2: Advantages and disadvantages of joint and separate studies for interruptions and voltage disturbances, and of joint study for all customer groups versus separate studies

	Advantages	Disadvantages
Joint study	• Cost effective • Comparable cost estimates	• Large budget has to be available for one study
Separate studies	• Only smaller budgets needed per study • Experiences from early study can be transferred	• Costly in total • Cost estimates change over time

The choice of the consultants is explained more in detail in the guidelines regarding interruptions and voltage disturbances. But some aspects have to be considered from a broader perspective. It can be advantageous to consider the same consultant for interruptions and voltage disturbance as well as for the various customer groups. If the same consultant performs the work, it is assured that the same approaches are applied and that the comparability of the results are given. This might support the choice of joint studies.

1 GUIDELINE FOR CONTINUITY OF SUPPLY

The typical sequence of a cost estimation study for interruption cost studies is presented in the following flow chart. The flow chart is divided into a survey based approach and a case based approach. Survey based approaches include typically 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 are applied to find the costs of interruptions of different customer groups. For each customer group it is proposed to use either the survey based or the case based approach, but in theory both approaches could also be used in parallel for one and the same customer group.

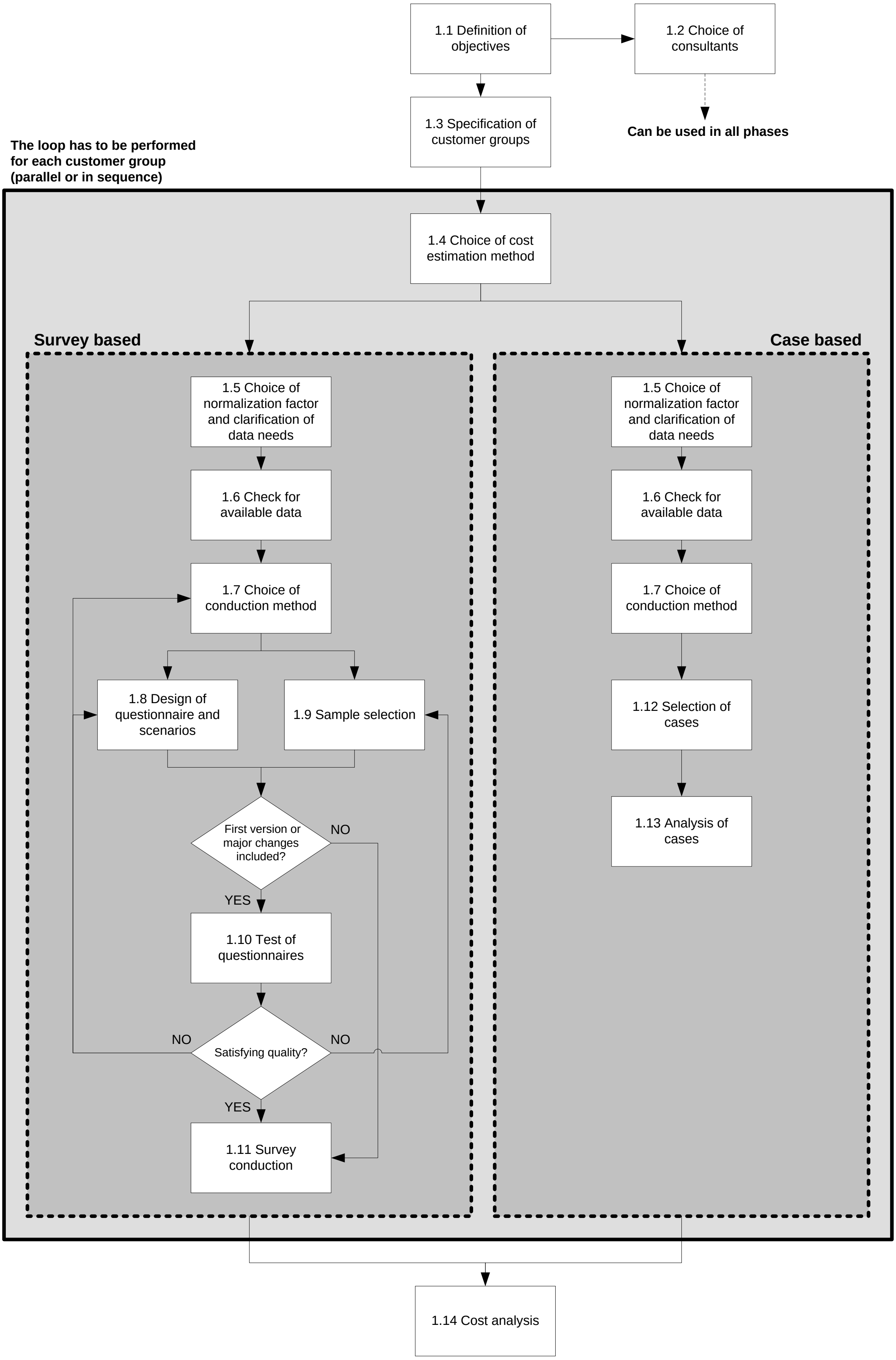

Figure 2: Flowchart for cost estimation study of interruptions

A checklist is presented in the following table to allow for checking critical points for each step of the cost estimation study.

Table 3: Checklist for 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?

1.1 DEFINITION OF OBJECTIVES

The first part of conducting a customer survey on costs related to continuity of supply is to set up a clear objective for the use of the results from a survey. For which purposes will the results be used:

- General knowledge about customer valuation of continuity of supply?
- Cost data for penalty schemes or other types of financial incentive based regulation?
- Cost data as basis for development of guaranteed standards?
- Provision of cost data for planning, operation and maintenance purposes for network companies and transmission system operators? E.g.: Basis for concession applications
- Is it important to cover all types of customers or is the objective to gather knowledge for specific groups of customers, i.e. focus the survey towards specific groups?
- What kind of interruptions and voltage disturbances are important to investigate?
- Etc.

The objectives of the survey give guidance for the information and data to be collected and the design and dimension of the questionnaire. The time, resource and budget needs are closely connected to the objectives, and have therefore to be evaluated and estimated at the start of the survey. A very confined budget can also limit the choice of objectives, since it could make it impossible to achieve an objective.

1.2 CHOICE OF CONSULTANTS

Consultants are usually used for parts of or even for the complete cost estimation study. If the consultant is used for the complete cost study, he is responsible for all study phases. In common, there are three typical tasks where consultants can be used if they are not responsible for the whole study; the design of the questionnaires, conduction of the survey and the cost analysis. 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 survey can be selection of the conduction method and of the sample. If a consultant is responsible for the cost analysis, he could also decide on the normalization of the data. The consultant needs different expertise for the different tasks and the competence and experience of the consultant has to be checked, before he is used for one of those tasks.

Design of questionnaires
The consultant needs experience in the design of questionnaires, knowledge of the survey methodology as well as technical and economical understanding of continuity of supply. Survey experience of related surveys is an advantage.

Conduction of the survey
The consultant needs survey experience and the resources as well as the technology available to conduct a major survey. This depends on the choice of conduction method, see below.

Cost analysis
The consultant needs technical and economical background and the mathematical competence to perform quality assurance of data, normalization, complex statistical analysis and regression analysis.

1.3 SPECIFICATION OF CUSTOMER GROUPS

SINTEF recommends the following grouping for a cost estimation survey:

- Households
- Commercial services (without “Infrastructure”)
- Public services (without “Infrastructure”)
- Industry (without “Large customers”)
- Large customers
- Infrastructure.

Alternative groupings are possible depending on the objective of the cost estimation survey (e.g. focus on some customer group) and country-specific factors (e.g. importance of agriculture for the economy). Examples of alternative groupings are as follows.

Alternative 1:

- Households
- Industry
- Commercial services and Public services.

This should be understood as minimum requirement of groups if the cost estimation survey shall cover all types of customers. It is not possible to merge the customer groups even more since the characteristics of these groups and the consequences of quality of supply problems to them are so different.

Alternative 2:

- Households
- Commercial services (without “Infrastructure”)
- Public services (without “Infrastructure”)
- Industry (without “Large customers” and “Agriculture”)
- Agriculture
- Large customers
- Infrastructure.

The proposed customer grouping should be connected to the statistical classification of economic activities in the European community (NACE Rev.2). The following table shows how the statistical categories are represented in the customer groups. A more detailed table with the sub categories of the NACE groups can be found in the appendix.

Table 4: NACE and customer groups

	Name	Customer group
A	Agriculture, forestry and fishing	Industry
B	Mining and quarrying	Industry
C	Manufacturing	Industry and Large customers
D	Electricity,gas,steam and air conditioning supply	Industry
E	Water supply;sewerage,waste management and remediation activities	Industry and infrastructure
F	Construction	Industry
G	Wholesale and retail trade;repair of motor vehicles and motorcycles	Commercial services
H	Transportation and storage	Commercial services and Infrastructure
I	Accommodation and food service activities	Commercial services
J	Information and communication	Commercial services and Infrastructure
K	Financial and insurance activities	Commercial services
L	Real estate activities	Commercial services
M	Professional, scientific and technical activities	Commercial services
N	Administrative and support service activities	Commercial services
O	Public administration and defence;compulsory social security	Public services
P	Education	Public services
Q	Human health and social work activities	Public and Commercial services
R	Arts, entertainment and recreation	Public and Commercial services
S	Other service activities	Commercial services
T	Activities of households as employers;undifferentiated goods- and services-producing activities of households for own use	Households
U	Activities of extra territorial organisations and bodies	Commercial services

1.4 CHOICE OF COST ESTIMATION METHOD

SINTEF recommends using the following cost estimation methods and corresponding conduction methods for the different customer groups as presented in Table 5. An explanation of the different methods with advantages and disadvantages of each method can be found in the state of the art section of the report (Part B Chapter 1.1).

If two alternative methods are applicable for one customer group, it is shown by alternative A and alternative B. It means that either the method marked with A or the method marked with B has to be used. A triangulation of several methods has to be applied, if several methods are marked with an A for one customer group. These methods have then to be used simultaneously in a triangulation approach. Possible alternative methods which can be included or applied are marked with brackets.

Table 5: Recommended cost estimation and survey conduction method for interruptions[4]

		Households	Commercial services	Public services	Industry	Large customers	Infra-structure
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
Conduction method (country specific)	Postal	B					
	Telephone	A				A	A
	Web	B	A	A	A		
	Face-to-face					A	A

A – Alternative A
B – Alternative B
( ) – Possible to include/use

SINTEF recommends triangulation using various cost estimation methods for two customer groups (alternative A for Households and Public services). The main idea is to collect cost estimates for monetary costs with the Direct worth method and to supplement with other methods which also cover non-monetary costs. The costs of the households can be estimated with two approaches which should be used exclusively (alternative A or B). It can be expected that Conjoint analysis (alternative B) delivers more reliable cost estimates. But one has to be aware of some drawbacks (see part B for details), before deciding for this alternative. It will for instance be difficult to compare results with the other customer groups, since differences in the cost estimates are also due to the different cost estimation methods. In that case alternative A should be preferred. In general, one should choose a method which is consistent with earlier surveys (if conducted) and other customer groups. But Conjoint analysis can be chosen, if this is the first study for Households or former surveys are conducted with Conjoint analysis, and the main objective is to get most reliable results for Households.

The estimation of spill-over costs and therefore the total socio-economic costs are not addressed directly here. Usually, these approaches have to include several customer groups, because spill-over costs are not limited to one customer group. Several approaches can be used and they are presented more in detail in Part B chapter 1.3.3.

The recommendation of conduction methods is already presented here, because they are closely connected to the chosen cost estimation method[5]. The conduction method may be highly country specific and the proposed methods have to be carefully considered on a national level.

[4] The issue of advance contact for identifying the right contact person is not addressed by the table. More details about this issue can be found in 1.7 Choice of conduction method.
[5] A more detailed description of the conduction methods is carried out in 1.7 Choice of conduction method.

1.5 CHOICE OF NORMALIZATION FACTOR AND CLARIFICATION OF DATA NEEDS

The cost estimates from the respondents in a survey are usually stated in absolute cost for a given interruption. The raw (surveyed) data need to be transformed into normalized data that can be used to represent customers within the same sector (i.e. with similar cost characteristics and different electricity consumption level) and to provide cost data on a usable form for different applications.

SINTEF recommends using a factor based on electricity demand/load shown in Table 15 in part B, preferably a constant such as annual electricity consumption, average load, peak load or interrupted power:

- Annual electricity consumption [kWh]
- Average load = annual electricity consumption/8760 [kWh/hr = kW]
- Peak load = the average load in the hour of the year with highest consumption [kWh/hr = kW]
- Interrupted load at reference time, i.e. the hourly load at the reference time of the survey [kWh/hr = kW]
- Energy not supplied, i.e. the estimated energy that would have been supplied if the interruption did not occur (kWh).

The first four on this list can be regarded as constants.

The choice of normalization factors should be seen in connection with the use of the cost data and the available data in the actual project at that time. This can be country-specific. Annual electricity consumption is usually available from the customers themselves or can be imputed based on available information about electricity bills and tariffs. Information about peak load or load at reference time are usually not publicly available but can be estimated from load curves. If load curves are available for individual customers or if general and credible load curves exist, such estimation will be possible. This is described in Chapter 3.2 in part B.

An alternative to annual electricity consumption is the energy not supplied as described in part B of the report. This parameter needs however to be estimated based on load curves. Energy not supplied varies by season, time of day and day of week. This variation needs to be taken into account together with the time variation in costs (see part B for details).

When the normalized data will be used to calculate interruption costs for a given customer belonging to the same category the normalized cost data should be used together with data for the customer corresponding to the normalization factor as illustrated below:

Normalized cost for category *s*

$$c_{N,s}(r,t) = \frac{C_s(r,t)}{N_s(r,t)} \quad [€/kWh \text{ or } kW]$$

Absolute cost for customer *k* of category *s*

$$C_k(r,t) = c_{N,s}(r,t) \cdot N_k \quad [€]$$

The normalized cost data for sector *s* for duration *r* at time *t* is $c_{N,s}(r,t)$. This should be used to calculate the absolute cost for a specific customer *k* belonging to the same category using data for the customer corresponding to the normalization factor, i.e. N_k. See part B for details.

1.6 CHECK FOR AVAILABLE DATA

It is important to reduce the number of questions in the questionnaire for the survey based approach to the minimum required to reveal the necessary data for the purpose. This will be beneficial both for the resources and time needed for the survey, but also for the expected response rates. It is also useful to check for available data in the case based approach to minimize the time needed for the interviews and time spent at the location of the business.

There might be available data about for instance electricity consumption, continuity of supply levels (number of short and long interruptions, interruption duration etc.), tariffs and others, that can be used in the survey instead of including these aspects in the questionnaire itself. Information about customer groups might be available from databases with contact information of companies, household panels, national bureau of statistics or other.

1.7 CHOICE OF CONDUCTION METHOD

The conduction method has to be chosen according to the cost estimation method and country-specific characteristics. Table 5 in chapter 1.4 shows the recommended conduction methods according to the cost estimation method. Conduction methods may be highly country specific and the proposed methods have to be carefully considered on a national level. The recommendation as presented here is adapted mainly to Northern and Central European countries, since SINTEF is most familiar and experienced with cost estimation studies in these countries. The main advantages and disadvantages of the different conduction methods are presented in Part B chapter 2.4.

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 it can be obtained an acceptable response rate in a cost efficient way. Response rates, especially from Households, can also be increased by implementing some kind of incentives for answering the questionnaires. SINTEF recommends approaching Households by telephone since it gives higher response rates than mailed questionnaires. But the telephone approach is not feasible if Conjoint analysis is chosen as cost estimation method due to the complex questionnaire design. The right contact persons in all customer groups except Households can in general be identified by telephone and/or email.

Summarized SINTEF recommends the following conduction methods for the different customer groups.

Households
The customers should be approached by telephone. If Conjoint analysis is chosen as method, a postal and/or web-based approach has to be chosen due to the complex questionnaire design.

Industry, Commercial services and Public services
These customer groups should be approached by web-based questionnaires. The contact person should be identified by phone in a first step to assure that the person with the right competence is addressed. A common procedure to increase the response rate in surveys is to use a "phone – e-mail/mail – reminder" approach. The respondents should be reminded to answer the questionnaires after a period of two weeks.

Large customers and Infrastructure
These customer groups are quite demanding to survey and since the cost estimation should be based on case studies, a face-to-face interview is recommended. But also interviews by telephone are possible. The right contact person can be identified in advance by telephone or e-mail.

1.8 DESIGN OF QUESTIONNAIRE AND SCENARIOS

The questionnaire should contain two parts; one asking for the specific customer characteristics, and one asking for the cost estimates for different interruption scenarios. Two examples of questionnaires for Households and Industry respectively can be found in the appendix.

1.8.1 Questions for customer characteristics

The customer characteristics have to be asked for with several questions, if not already available from other data sources. Besides the customer group specific characteristics, some general characteristics have to be collected from all customer groups. In the following the most important general and customer group specific characteristics are presented.

General characteristics which have to be asked are:
- Region (urban/rural and climate)
- Customer experience with interruptions
- Customer satisfaction regarding continuity of supply
- Electricity consumption and bill.

Special characteristics depending on the customer group:
- Households
    - Number of residents
    - Type of housing
    - Households income

    - Special activities/circumstances (home business, sickbed resident, medical equipment)
- Commercial services
    - Sector
    - Number of employees
    - Turnover
    - Number and types of customers
    - Backup possibilities
- Public services
    - Sector
    - Number of employees
    - Backup possibilities
- Industry
    - Sector
    - Number of employees
    - Turnover
    - Number and types of customers
    - Backup possibilities
- Large customers and Infrastructure
    - Individual characteristics of the chosen cases.

1.8.2 Cost estimation scenarios

SINTEF recommends using the following interruption scenarios and attributes. Interruption scenarios should contain the following attributes:

- Time of occurrence
    - time of day (e.g. 6 am, 12 am, 6 pm, 12 pm)
    - day of week (e.g. working day, Saturday, Sunday)
    - season (e.g. winter, summer, autumn/spring)
- Duration (e.g. 1 s, 1 min, 1 h, 4 h, 8 h, 24 h)
- Advance warning (yes, no)

Frequency is not included as an attribute. It can be expected that the cost of a single event are quite similar and only slightly dependent on the frequency of occurrences. Compared to other attributes, the effect of frequency should be insignificant. Nevertheless, the total cost over a time period as for example a year is highly dependent on the number and therefore the frequency of quality of supply problems. But the total costs can be calculated based on the cost of single events, where all the other attributes besides frequency are covered.

The number of scenarios should not exceed 10 per customer and should cover the whole spectrum of the attribute values, as well as a worst case scenario.

Worst case scenarios
SINTEF recommends describing a reference scenario with a worst case timing when the consequences are expected to be highest. This will also give information about an upper bound of the costs. The worst case scenario is different for each customer group and also country specific. It has to be analyzed when the different customers are most dependent on electricity supply. This can be done by studying the power demand curves of the customers, if one accepts the assumption that electricity consumption and costs are directly related. Another approach is to analyze the activity pattern of the customers, for example when they are producing most (Industry) or when they usually want to watch TV (Households). If the information needed for estimating the electricity demand curve or the activity pattern of a customer group is lacking, the worst case scenarios has to be identified directly with the customers. A focus group is an adequate method to do so.

Based on the attributes described earlier general worst case scenarios for the different customer groups will be presented as far as possible.

- Households
  - Season: Summer or winter (depending on if electricity is used for heating or cooling purposes and the climate of the specific country)
  - Day of the week: Weekday (has to be seen in connection with time of the day, on weekdays households are not that flexible to shift activities to another time at the day)
  - Time of the day: Evening (People are usually at home, dependent on light, watch TV or preparing food)
- Commercial services (without “Infrastructure”)
  - Season: Month with high activity (maybe end of the year since a lot of projects usually end with a year)
  - Day of the week: Working day
  - Time of the day: Working hours
- Public services (without “Infrastructure”)
  - Season: Month with high activity (maybe time before an important deadline as the submission of the tax declarations)
  - Day of the week: Working day
  - Time of the day: Working hours
- Industry (without “Large customers”)
  - Season: Month with high activity (dependent on the industry sector)
  - Day of the week: Working day
  - Time of the day: Working hours
- Large customers
  - The worst case scenarios are best identified in direct contact with the large customers, because their specific characteristics have to be considered.
- Infrastructure
  - The worst case scenarios are best identified during the conduction of the case study in direct contact with the customer, since these customers have very special and different characteristics.

The formulation of the questions and the design of the questionnaire is dependent if Direct worth and Contingent valuation (eventually preparatory action method) or Conjoint analysis is applied. Another fact which has to be considered is that there is a difference between asking about costs that will follow after a certain event on the one hand, and costs of being exposed to the risk of those events (ex ante) on the other hand. If it is a goal to capture the option value, the scenarios should be of the second type.

Direct worth
In the Direct worth method customers are asked to estimate the direct costs which incur due to an interruption. Predefined cost categories should be used. Examples of possible cost categories and consequences for the different customer groups are presented in the following.

Households
- Lost food in freezer/refrigerator
- Damaged equipment
- Lost computer data
- Reprogramming of electronic devices
- Uncomfortable indoor temperature
- No light
- No possibility to cook
- Interruption of leisure activities
- Home office / PC can not be used
- Higher risk of accidents
- Higher risk of being exposed to burglary.

Industry
- Lost production
  - Production which can not be recovered
  - Savings, for example raw materials, have to be considered
- Costs of the alternative to production lost
  - Additional overtime to recover lost production time
  - Buying products/services from another producer
- Damage to equipment, products and raw material
- Re-start costs
- Costs of penalty payment
- Direct costs associated with human health and safety.

Commercial services and Public services
- Lost working time
- Costs for overtime work
- Costs of recovering data
- Damage to equipment and products
- Costs of penalty payment
- Direct costs associated with human health and safety.

The cost estimation of different scenarios can be based on either absolute or relative cost estimates in Direct worth surveys. Both approaches are usable and also a combination of both can be used in the questionnaire. Absolute cost estimate means that the respondent is confronted with different interruption scenarios and has to state a cost estimate for each of the scenarios independently. In the following an example is presented.

If an electricity interruption occurs with the following characteristics, what would be the costs for your company? Duration: 1 hour Season: January Day of week: working day Time of day: 6 pm Warning: no advance warning	
A	Lost production (minus savings):
B	Costs for making up production (overtime, etc.):
C	Costs for delayed delivery (fines, etc.):
D	Damage to raw materials and finished products:
E	Damage to equipment:
Sum of all costs [€]:	
If an electricity interruption occurs with the following characteristics, what would be the costs for your company? Duration: 2 hour Season: July Day of week: working day Time of day: 6 am Warning: no advance warning	
A	Lost production (minus savings):
B	Costs for making up production (overtime, etc.):
C	Costs for delayed delivery (fines, etc.):
D	Damage to raw materials and finished products:
E	Damage to equipment:
Sum of all costs [€]:	

Figure 3: Example absolute scenarios

Relative cost estimates are given related to a reference scenario. The respondent has to quote a change in costs dependent on a change in the scenario attributes. In the following an example is presented.

Assume that an electricity interruption occurs at 10 am on a Thursday in January without advance warning and lasts for 1 hour. Estimate the cost of this interruption.									
A	Lost production (minus savings):								
B	Costs for making up production (overtime, etc.):								
C	Costs for delayed delivery (fines, etc.):								
D	Damage to raw materials and finished products:								
E	Damage to equipment:								
Sum of all costs [€]:									
If the interruption occurs at another time than 10 am, what would the cost be relative to that scenario?									
	Lower costs					Higher costs			
	-100 %	-75 %	-50 %	-25 %	0 %	+ 25 %	+50 %	+75 %	+100%
6 am									
12 am									
6 pm									
12 pm									

Figure 4: Example relative scenarios

Contingent valuation

In Contingent Valuation questions the respondent is presented with a hypothetical scenario of an interruption, and asked for the willingness to pay for avoiding it or willingness to accept compensation, to be indifferent to the welfare losses in the scenario. SINTEF recommends including at least one Contingent valuation question for one scenario for the customer groups in question (Households and Public services). Examples on how to formulate willingness to pay and a willingness to accept questions are presented following.

Assume that hypothetically a reserve power supply is available that could supply the entire household's electricity needs during an interruption. The reserve supply is purchased only for the time actually in use. How much would you be willing to pay for such a service to maintain power supply during an interruption with the following characteristics and thus avoid the cost of the interruption? Duration: 2 hour Season: July Day of week: working day Time of day: 6 am Warning: no advance warning
Willing to pay for the service [€]:

Figure 5: Example willingness to pay

Assume that the network company informs you about an interruption, just before the interruption will occur (no time for preventative actions). You can choose whether you will accept the power interruption and simultaneously receive a financial compensation, or whether the power supply is not switched off and you may continue to use electricity as before. What is the minimum amount of compensation you would need to accept a power interruption with the following characteristics? Duration: 2 hour Season: July Day of week: working day Time of day: 6 am Warning: no advance warning
The minimum compensation is [€]:

Figure 6: Example willingness to accept

Conjoint analysis

In Conjoint analysis, customers are asked to select the preferred alternative between pairs of hypothetical scenarios, or they may be asked to rank or rate a list of different hypothetical scenarios. The scenarios are built up by several attributes. The price can be included as an absolute value or relative to the current electricity bill as in the example. Respondents are presented with several scenarios, where attributes are slightly changed from scenario to scenario, such that preferences for various components or attributes can be examined at a more refined level. The example shows a vignette with a relative price change and where the scenarios has to be rated. In that example, the respondent has to give a rating mark to the presented scenarios to state his/her preferences. The respondent is therefore not only confronted with pairs of scenarios, but with a number of scenarios he/she has to rate one by one.

Single-outage: Series A, card 1	
Duration of the outage	2 h
Day of the week	Wednesday
Part of the day	In the afternoon (12 p.m. till 6 p.m.)
Season	Summer
Warning in advance	Without warning
Change in electricity bill	5% discount
Rating mark	–

Figure 7: Example for a scenario in Conjoint analysis (Source: Baarsma and Hopp 2009)

1.9 SAMPLE SELECTION

After the survey has been designed it has to be decided which sample size of respondents should be selected to obtain a representative sample. It is necessary that the sample provides a good representation of the customer groups and in sub-samples of interest and is closely connected to the response rate of the customers. This is particularly important since cost estimates can vary considerably between different individual customers. Typical response rates and standard deviations can be derived from former cost estimation surveys[6]. A best guess has to be used if no data are available. This can be adjusted after the pilot study since more information on expected response rate and standard deviation of the cost estimates then is available.

The following steps should be performed to select a representative sample:

1. Definition of the original population
2. Dividing into sub-groups with stratified sampling
3. Definition of the sample size of the sub-groups
4. Sample selection in the sub-groups with random sampling.

The original population can be defined through industrial classifications and databases, power company customer lists, address registers or other databases as the white or yellow pages. If the original population is defined, it can be divided into sub-groups with stratified sampling. The stratification of the sub-groups should be based on the statistical classification of economic activities in the European community (NACE) or a similar country specific classification. NACE has a quite detailed level. The first level of the sub-groups in the category manufacturing, which is part of the Industry customer group, can be seen in Table 6[7]. Of course, the number of sub groups has to be seen in relation to the volume and cost of the survey. A more detailed grouping will need more respondents, even though the sub groups have the same questionnaire. SINTEF therefore recommends balancing the number according to the needs of the survey[8]. Regardless of the needs, a complete use of all sub-groups based on NACE is not recommended; several groups may be combined. In general, only Industry, and Commercial services and Public services should be stratified.

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[6] Examples of response rates of former cost studies can be found in Figure 15.
[7] A more detailed list of the NACE categories and the first sub category can be found in the appendix.
[8] An example showing number of respondents needed according to the number of groups can be found in Part B Chapter 2.5.

Table 6: Sub categories of manufacturing according to NACE

C	Manufacturing
10	Manufacture of food products
11	Manufacture of beverages
12	Manufacture of tobacco products
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of wood and products of wood and cork; except furniture; manufacture of articles of straw and plaiting materials
17	Manufacture of paper and paper products
18	Printing of reproduction of recorded media
19	Manufacture of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of basic metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment n.e.c.
29	Manufacture of motor vehicles, trailers and semi-trailers
30	Manufacture of other transport equipment
31	Manufacture of furniture
32	Other manufacturing
33	Repair and installation of machinery and equipment

The sample size of the sub groups of Industry, Commercial services and Public services can be equal (proportionate stratification), but should be adjusted to the economical importance of the sub-groups (disproportionate stratification).

The sample size is directly dependent on the expected response rate which again is dependent on several factors. Besides country specific reasons, the length of the questionnaire, the number of scenarios and the type of survey conduction have a large influence on the response rate. The following formula can be used to get an approximate for the sample size depending on the expected response rate, the expected spread in the cost estimation and the requested significance of the results.

$$n = \left(\frac{S \cdot 2 \cdot Z_{\frac{\alpha}{2}}}{L}\right)^2$$

n – number of respondents needed
S – standard deviation
$Z_{\alpha/2}$ – Z-value depending on the distribution and the confidence level
L – Length of the confidence interval

$$N = \frac{n}{R}$$

N – Sample size
R – Response rate

In the following a general example is given for sample sizes based on the equation.

Confidence interval	± 25 % mean
Confidence level	95 %
$Z\alpha/2$	1.96 (assumes normal distribution)

General examples

Standard deviation (% of mean)	Response rate	Sample size
100 %	20 %	307
200 %	20 %	1229
300 %	20 %	2766
400 %	20 %	4917

Groups can also be combined to reduce the sample size. The decision to combine customer groups should be done on case-to-case basis. The main advantages and disadvantages of combining can be found in the state of the art in part B of the report.

After defining the sample size a representative sample can be drawn in the groups. SINTEF recommends using random sampling proportionally to the turnover of the customer for the Industry, Commercial services and Public services. It is often difficult to get representative cost estimates for larger customers with simple random sampling, since small customers are usually overrepresented in the population with simple random sampling and only a few cost estimates for Large customers can be obtained. Therefore random sampling proportionally to the turnover is recommended. The representative sample in Households should be drawn with simple random sampling.

1.10 TEST OF QUESTIONNAIRES

SINTEF recommends testing all aspects of the survey; first in a focus group or in direct contact with the respondent and secondly with a pilot study. A focus group consists of a selection of customers from the customer group of interest. They are asked in direct contact about there opinions about the questionnaire presented. Pilot surveys are conducted on the same premises as the final survey but on a smaller sample and has to be conducted for all customer groups. A recommended pilot study size is between 2 % and 10 % of the final study depending on the final size of the survey. The following aspects have to be tested:

- Scenarios understood and accepted
- Questions formulated in a clear way
- Range of answer values are representative
- Length of questionnaires
- Way of approaching the customer (conduction method)

In addition, an indication of expected response rates can be obtained through the pilot study, which is a useful input to decide on the final sample size. Based on the experience of the pilot study, it has to be checked how realistic the estimates are for the time, resources and budget needed for performing the final survey. Eventually, adjustments have to be undertaken.

1.11 SURVEY CONDUCTION

The timing of the survey is in common not dependent on the seasons of the year. Generally, a survey can be conducted at any time of the year. But it can be worthwhile to avoid point in times when the respondents are busy as at the end of the year or not easily available as in holiday periods. The duration for conducting a survey is approximately two months, which includes reminders to customers which did not answer to the first contact approach. As described earlier the following conduction methods are recommended by SINTEF for the different customer groups:

Households
The customers should be approached by telephone. If Conjoint analysis is chosen as method, a postal or web-based approach has to be chosen due to the complex questionnaire design.

Industry, Commercial services and Public services
These customer groups should be approached either by postal or web-based questionnaires. The contact person should be identified by phone in a first step to assure that the person with the right competence is addressed. A common procedure to increase the response rate in surveys is to use a “phone – e-mail/mail – reminder” approach. The respondents should be reminded to answer the questionnaires after a period of two weeks.

1.12 SELECTION OF CASES

Several case customers have to be chosen from the customer groups Large customers and Infrastructure to perform a case based cost study. The customer in question for the case study has to fulfil several criteria. When the customer is contacted it should always be checked if the customer has employees with electro-technical background and an overview of electricity dependent processes as well as backup solutions. This competence is needed to evaluate the consequences of interruptions. In addition, only cases should be selected where the customer seems interested in performing such a study and therefore is willing to participate actively in the study. In addition, the customer in question for the case study should be representative for a type of Large customers or Infrastructure. The whole spectrum of Infrastructure customers and Large customers should be covered.

1.13 ANALYSIS OF CASES

Large customers and Infrastructure
The case studies have to be performed by telephone interviews or face-to-face interviews at the location of the business. The right contact person or persons can be identified in advance by telephone or e-mail. The interviews can be supported by interview guidelines and prepared short questionnaires to collect data of the general characteristics of the customers including region (urban/rural and climate), customer experience with interruptions, customer satisfaction regarding continuity of supply, and electricity consumption and bill. The hypothetical scenarios which are used to analyse the consequences of interruptions in the case companies have to be consistent with some of the scenarios in the survey based approach.

1.14 COST ANALYSIS

Preparation and normalization of the raw data collected through the survey is described thoroughly in part B of the report together with a description of how to provide usable cost estimates for the different customer groups. In the following a brief description is given of quality assurance, normalization and handling of outliers.

Quality assurance of raw data
The raw data collected through the questionnaire should be examined for wrong and missing data and if the real responses are representative of the random samples. SINTEF recommends executing logical tests in the data material and exclude careless responses and misinterpretations from the sample for the particular question:

- If the respondent has reported costs exceeding the annual turnover – exclude the data for this respondent from the sample for the specific question (scenario)
- If the respondent has reported higher willingness to pay (WTP) values than willingness to accept (WTA) or Direct worth values – exclude the data for this respondent from the sample for the specific question (scenario)

- If the annual electricity consumption given does not correspond to the electricity bill for the same year - exclude the data for this respondent from the sample for the specific question (scenario).

Zero values in willingness to pay estimate combined with very high Direct worth and willingness to accept estimates (normalized data) compared to other respondents of the same customer group indicate protest answers. In this case all cost estimates of the respondent should be excluded from the data set for the specific question. This aspect should be included in the logical tests.

SINTEF recommends imputation of missing data about electricity consumption if possible. It can be calculated from the electricity bill for the whole year divided by the tariff (sum of energy cost tariff and network tariff). In cases where electricity consumption is missing both in terms of kWh and in monetary terms, the consumption may be estimated using representative load curves.

It is recommended to perform statistical tests on the material to reveal if the real sample is representative for the random samples since lack of responses (low response rates) might give misleading estimates in case of systematic repeal.

Normalization
The individual raw data should be normalized after quality assurance to make them comparable within the different customer groups, using normalization factors as described in Chapter 1.5. The normalized data are used to calculate arithmetic means of the costs for the various scenarios and for the different customer groups.

Handling outliers and zeroes
SINTEF recommends in general to treat the zero costs in the material as zero values and not to exclude them from the material except for those zeroes indicating protest answers. It is therefore important not to substitute missing values by zeroes in the tools used for data analysis of the collected data.

Furthermore SINTEF recommends no censoring of outliers from the material, but to present the whole distribution of the normalized data together with different measures of dispersion such as standard deviation, maximum and minimum values, percentiles etc.

2 GUIDELINE FOR VOLTAGE DISTURBANCES

Collecting data for 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 but to know the difference and recognize transients, voltage swells, voltage dips, harmonics, unbalance etc. is something the vast majority of electricity customers simply is not capable of. A typical approach to estimate the cost of voltage disturbances is presented in the following flowchart. The cost can be estimated either by a survey based or by 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 voltage disturbances for these typical cases. Both approaches are applied to find the costs of voltage disturbances for different customer groups. For each customer group it is proposed to use either the survey based or the case based approach, but in theory both approaches could also be used in parallel for one and the same customer group.

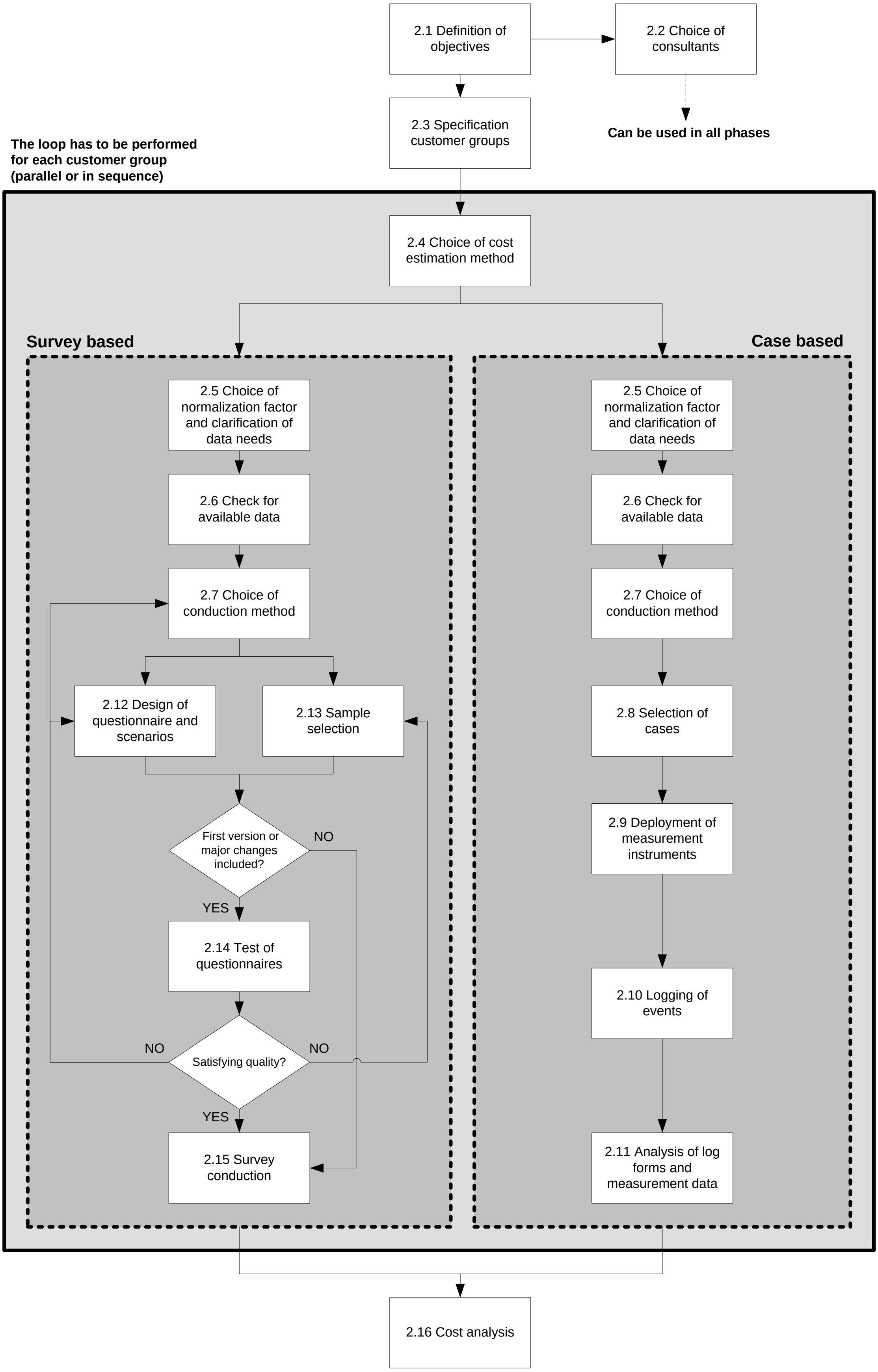

Figure 8: Flowchart for cost estimation studies of voltage disturbances

A checklist is presented in the following table to allow for checking critical points for each step of the cost estimation study.

Table 7: Checklist for 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?
	Has the customer received information and training about his/her 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 has 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?

2.1 DEFINITION OF OBJECTIVES

The first part of conducting a study on estimation of costs related to voltage disturbances is to set up a clear objective for the use of the results from a survey. For which purposes will the results be used:

- General knowledge about customer valuation of voltage disturbances?
- Cost data for penalty schemes or other types of financial incentive based regulation?
- Cost data as basis for development of guaranteed standards?
- Provision of cost data for planning, operation and maintenance purposes for network companies and transmission system operators?
- Which types of customers and which phenomena are important to cover, i.e. focus the study towards specific groups and specific phenomena?
- Etc.

Experiences in several countries show that voltage dips, voltage swells, transient overvoltages, harmonic voltages and supply voltage variations are causing highest costs for customers. The objectives of the survey give guidance for the information and data to be collected and the design and dimension of the questionnaire and case studies.

The time, resource and budget needs are closely connected to the objectives, and have therefore to be evaluated and estimated at the start of the survey. A very confined budget can also limit the choice of objectives, since it could make it impossible to achieve an objective.

2.2 CHOICE OF CONSULTANTS

If a consultant is chosen to execute parts or the complete cost study, the consultant needs a given scope of expertise. A high level of competence is needed within both economics and voltage quality. In addition to competence within economics, it is necessary that the consultant has both education and experience within electrical engineering and understands the technical aspects of voltage disturbances. Practical experiences with voltage quality, including troubleshooting, is not required although it might be an advantage. The consultant should be qualified to perform power quality measurements else such services must be hired from a third party. In addition, the consultant needs technical and economical background and the mathematical competence to perform quality assurance of data, normalization and complex statistical analysis. In general, the criteria mentioned for consultants for interruption cost studies are also valid for consultants for voltage disturbance studies (see Chapter 1.2).

2.3 SPECIFICATION OF CUSTOMER GROUPS

The customers included in a study of costs due to voltage disturbances need also some knowledge about these voltage quality problems. Industrial companies, infrastructure customers and large companies with their own personnel with electricity knowledge may be able to deliver good quality answers to consequences and costs due to at least some of the voltage disturbances.

However even such personnel may not always have detailed knowledge about voltage quality. Experiences so far indicate that not only household customers but even many customers within Commercial service and Public services have very little knowledge about voltage quality and how the different voltage disturbances affect them.

SINTEF recommends specifying the customer groups as for interruption studies in the following groups:

- Households
- Commercial services (without “Infrastructure”)
- Public services (without “Infrastructure”)
- Industry (without “Large customers”)
- Large customers
- Infrastructure.

SINTEF recommends focussing on Industry, Large customers and Infrastructure, since it can be expected to find sufficient knowledge about voltage disturbances and their consequences for the operations in these customer groups. Due to the large costs of such cost studies it is worthwhile to concentrate most of the effort on customer groups where it can be expected that it is possible to collect reliable cost estimates for voltage disturbances. The other customer groups can be asked in a qualitative manner for experienced consequences of voltage disturbances and some cost estimates can be collected by presenting really simplified scenarios of voltage disturbances.

2.4 CHOICE OF COST ESTIMATION METHOD

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. The case studies should include both measurements of voltage quality data and logging of events, problems and costs/consequences in a journal at the customers. The case based cost estimation approach is quite costly on a large scale and requires competent customers; Industry, Large customers, and Infrastructure. The consequences of voltage disturbances are quite complex and individual for Large customers and Infrastructure. That speaks also in favour for the case based approach for these customer groups. For all other customer groups, SINTEF recommends to develop simple scenarios for cost estimation and qualitative questions about the consequences of voltage disturbances in a questionnaire. In general the same survey based methods are recommended for Households (Direct worth and Contingent valuation, alternatively Conjoint analysis), Commercial services (Direct worth), Public services (Direct worth and Contingent valuation), and Industry (Direct worth) as in the guideline for interruption costs (see section 1.4). For Industry it can be decided if either the case based approach (alternative A) or the survey based approach (alternative B) is applied. It is also possible to use case based approach for some selected Industry customers and to do a survey based approach on the whole Industry sector.

In detail, SINTEF recommends the following methods for each of the customer groups as presented in Table 8. If two alternative methods are applicable for one customer group, it is shown by alternative A and alternative B.

Table 8: Recommended cost estimation and survey conduction method for voltage disturbances[9,10]

		Households	Commercial services	Public services	Industry	Large customers	Infra-structure
Cost estimation method	Survey based	A	A	A	B		
	Case based				A	A	A
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
B – Alternative B

SINTEF does not recommend using survey based cost estimation methods for Large customers and Infrastructure. The consequences of voltage disturbances are complex and diverse for the individual customers in the groups of Large customers and Infrastructure. A general survey could therefore not consider the individual characteristics of these customers. But of course, questionnaires can be used to structure the collection of background information of the different case companies when visiting them.

2.5 CHOICE OF NORMALIZATION FACTOR AND CLARIFICATION OF DATA NEEDS

SINTEF recommends using a load based normalization factor (in kW) for voltage disturbances similar to interruptions described in the guideline for continuity of supply surveys in Chapter 1.5.

Information about peak load or load at reference time are usually not publicly available but can be estimated from load curves. If load curves are available for individual customers or if general and credible load curves exist, such estimation will be possible.

If statistics of different voltage quality phenomena are available for different customer groups, it is possible to use the number of incidents and order of severity as normalization factors per customer group; for instance to calculate a cost per incident on average for a specific customer group: cost per voltage dip of certain depth and/or duration etc.

2.6 CHECK FOR AVAILABLE DATA

This phase is similar to the approach for interruption cost studies in section 1.6 and an explanation can be found there.

[9] The methods to be applied in the survey based approach are similar to the methods in Table 5: households (Direct worth and Contingent valuation, alternatively Conjoint analysis), commercial services (Direct worth), public services (Direct worth and Contingent valuation), industry (Direct worth).
[10] The issue of advance contact for identifying the right contact person is not addressed by the table. More details about this issue can be found in 2.7 Choice of conduction method.

2.7 CHOICE OF CONDUCTION METHOD

The conduction method has to be chosen according to the cost estimation method and country-specific characteristics. Table 8 in Chapter 2.4 shows the recommended conduction methods according to the cost estimation method. The conduction methods for the survey based approach are consistent with the proposed methods in the guideline for interruption cost studies. Case based studies have to be conducted by face-to-face or telephone interviews and measurement of voltage disturbances with simultaneous logging of the consequences. Summarized SINTEF recommends the following conduction methods for the different customer groups:

Households
The customers should be approached by telephone for the Contingent valuation approach. If Conjoint analysis is chosen as method, a postal and/or web-based approach has to be chosen due to the complex questionnaire design.

Commercial services and Public services
These customer groups should be approached with web-based questionnaires. The contact person should be identified by phone in a first step to assure that the person with the right competence is addressed. A common procedure to increase the response rate in surveys is to use a “phone – e-mail/mail – reminder” approach. The respondents should be reminded to answer the questionnaires after a period of two weeks.

Industry
The same conduction method as for Commercial services and Public services is proposed for the survey based approach. The case based approach should be conducted identical to the conduction method for Large customers and Infrastructure.

Large customers and Infrastructure
These customer groups are quite demanding to survey and since the cost estimation should be based on case studies, a face-to-face interview is recommended, but also interview by telephone is possible. The right contact person can be identified in advance by telephone or e-mail. The installation of the measurement equipment and the collection of the logging forms require also personal presence.

2.8 SELECTION OF CASES

The case based cost estimation study focuses on a sample of companies and collecting 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 assure that that the consequences can be assigned to different types of voltage disturbances, that is the great challenge in assessing the costs of voltage disturbance.

The customer in question for case study has to fulfil several criteria. When the customer is contacted it should always be checked if the customer has employees with electro-technical education and preferably also some experience with voltage quality. This competence is needed to evaluate the consequences of voltage disturbances. In addition, only cases should be selected where the customer seems interested in performing such a study and therefore is willing to participate actively in the study. Customers in areas where it is known or at least expected that the voltage quality is poor or at least moderate should be preferred to facilitate an effective data collection. In locations with little disturbances it may take weeks or even months to capture (measure) significant disturbances. This approach is feasible since these case studies are not to establish statistics on the voltage quality levels but to find the consequences from voltage disturbances when they occur.

An additional requirement can be the availability of voltage quality measurement at the customer's point of delivery as in the Italian study (Delfanti et al. 2010). But that should not be a general prerequisite since measurement instruments also can be deployed to the customers participating in the study.

2.9 DEPLOYMENT OF MEASUREMENT INSTRUMENTS

During case studies the voltage disturbances can be recorded with power quality measurement instruments ranging from typically 1000 € to several times that amount. Even instruments with as low cost as 1000 € can measure most EN50160 parameters, for example:

- Frequency of the supply voltage
- Supply voltage variations
- Voltage dip
- Voltage swells
- Rapid voltage change
- Flicker
- Transient overvoltages
- Harmonic voltage.

Measurement instruments have to be deployed to customers which does not have this measurement equipment available. A high quality three phase power quality measurement instrument capable of measuring almost all common voltage quality parameters are available at a price of 2000 – 4000 €. A high quality single phase 230 V voltage quality measurement instruments, also capable of measuring almost all common voltage quality parameters, is available at approximately 1000 €. Advanced three phase instruments should be used for the measurements in the Industry and at Large customers even though single phase measurement might be satisfactory for some of these customers. The three phase instruments have to be installed in or as close as possible to the point of common coupling. Low cost single phase instruments must be connected to a standard 230 V alternating current wall socket as close to the point of common coupling as possible.

2.10 LOGGING OF EVENTS

Voltage disturbances are automatically measured and stored in the measurement equipment. In addition, the cost and consequences of the experienced event has to be filled in a journal by one or a few employees in charge. The reported events in the journal should be registered when the customer experience damage to electrical equipment or malfunction of electrical equipment. The employees reporting events should have electro-technical education and preferably also some experience with voltage quality. If this person does not know the costs caused by the experienced problems administrative personnel at the company should be involved in estimating the costs based on the problems they experience. The cost and consequences have to be specified for each event and the event should be logged with good time resolution; preferably one minute or less.

The duration of the case studies (measurements/logging) should if possible last long enough for voltage disturbances actually causing problems for the customer to occur. This can not always be verified before the measurements and the log is analyzed so the measurements and logging should preferably last long enough for more than one event to be logged and more than one voltage disturbance to be measured. Depending on the voltage quality level in the selected measurement locations, this may take several months. In some cases such a measurement period may be too long for practical studies. For this reason it should be preferred performing case studies in areas where it is known or expected that the voltage quality is poor or at least moderate. It has to be considered that customers in these areas may have installed UPS systems to protect their equipment and processes. In this case, customers with a low internal protection level should be preferred for the measurement campaign. An alternative is to choose some customers from areas with better voltage quality, if no customers with low protection are available in the areas with poor/moderate voltage quality. Then the duration of the measurement and logging campaign may have to be significantly longer to register voltage disturbances with clear consequences and costs.

2.11 ANALYSIS OF LOGGING JOURNALS AND MEASUREMENT DATA

After the measurement period the data from the instruments and logging journals have to be collected. The logged events in terms of cost and consequences have to be evaluated against the voltage quality measurements. This ensures that consequences can be connected directly to different types of voltage disturbances.

2.12 DESIGN OF QUESTIONNAIRE AND SCENARIOS

In general, the questions developed for voltage disturbances and their consequences can be included in the interruption questionnaire or can be developed as a stand alone questionnaire. If a stand alone questionnaire is used, the questions for the general characteristics of the customer, as described in section 1.8.1, have to be included. When performing a questionnaire survey it is necessary to do this with carefully selected simplified scenarios for cost estimation of 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 categories. It can be expected that almost all household customers have no competence on voltage quality. The questionnaire for household customers as well as commercial and public customers should furthermore be focussed more towards the consequences (from voltage disturbances) rather than the voltage quality parameters themselves.

In the following proposed questions are presented to assess consequences of voltage disturbances.

Households

Below possible consequences of voltage disturbances are listed. Has your household suffered some of these phenomena over the past year?

- Damage to electrical equipment and appliances
- Malfunction of electrical equipment including lighting control equipment
- Reduced light output
- Poor lighting quality (flicker)
- Short life time of light bulbs
- Tripping of computers and other electrical equipment.

Industry, Commercial services and Public services

Below possible consequences of voltage disturbances are listed. Has your company suffered some of these phenomena over the past year?

- Malfunction in computer systems
- Problems with starting electric motors
- Malfunction in process control systems
- Electric motors disconnected from electricity network of the motor protection
- Short life time of light bulbs
- Electrical equipment gets hot.

For a non-technical electricity customer some of the voltage disturbances can be seen as similar to very short interruptions (e.g. 1 s). Thus, they can be included in cost studies in that way as this might be more meaningful or understandable to a respondent than different technical terminology for voltage disturbances. A combination of a very simple educational description of voltage disturbances and especially what problems they might cause can be the best solution. Then the customers can relate to what problems and consequences they may experience and connecting these consequences to the different voltage disturbance parameters can be quality assured partly by thoroughly selecting a few appropriate scenarios and partly by quality assurance during survey result analysis.

A few examples of important scenarios that can be used:

1. Damage to electrical equipment due to short duration overvoltages (transients and swells)
2. Malfunction (trip) of electrical equipment due to short under-voltages (voltage dips)
3. Malfunction (or damage) due to long time undervoltage
4. Unstable lighting due to flicker and/or rapid voltage changes.

Scenario 1: Damage to electrical equipment due to overvoltages
Get the customer to estimate the costs related to damage to different kinds of electrical equipment in his/her installation. Such damage can then be connected to transient overvoltages or serious voltage swells. The size of the selected disturbances must be chosen such that the probability of damage to electrical equipment/appliances is relatively high (e.g. +20 % voltage swell for 1 second and/or 3 kV 1.2/50 µs lightning impulse). This scenario should not be very difficult to relate to for any of the customer categories, but can still cause some errors due to e.g. customers mixing damage of electrical equipment from very large harmonic voltages with damage due to voltage swells and transient overvoltages.

Scenario 2: Malfunction (trip) of electrical equipment due to short undervoltages (voltage dips)
This scenario will be closely related to interruptions. The customers must specify the consequences/costs for a voltage dip of a certain depth and duration. Preferably it should be used at least two different durations and depths (for example one large dip and one moderate or small dip). The selected duration of dips should be tied to documented levels of dips in the network. This scenario could also be used with all customer categories. It can however be some of the customer categories where the customers might have difficulties by differentiating between a very short interruption and a voltage dip.

Scenario 3: Malfunction (or damage) due to long time undervoltage
This scenario may include low lighting levels, poor power output and even a low to moderate level of damage to equipment.

Scenario 4: Unstable lighting due to flicker and/or rapid voltage changes
This scenario may be very interesting to include from the point of view that a high percentage of the customer complaints (in some countries) are related to these disturbances. It is however very important to be aware of the challenges related to putting a value on voltage disturbance that mainly cause annoyance/irritation and not damage or malfunction to electrical equipment.

2.13 SAMPLE SELECTION

This phase is similar to the sample selection phase in the interruption cost guide. The representative sample for the conduction of the survey has therefore to be selected as described in the interruption cost estimation guide in section 0.

2.14 TEST OF QUESTIONNAIRES

This phase is similar to the approach for interruption cost studies in section 1.10 and an explanation can be found there.

2.15 SURVEY CONDUCTION

This phase is similar to the approach for interruption cost studies in section 1.11 and an explanation can be found there.

2.16 COST ANALYSIS

Preparation and normalization of the raw cost data is described thoroughly in part B of the report together with how to provide usable cost estimates for the different customer groups. In the following a brief description is given of quality assurance, normalization and handling of outliers.

Quality assurance of raw data
The raw data collected through the questionnaire should be examined for wrong and missing data and if the real responses are representative of the random samples. SINTEF recommends executing logical tests in the data material and exclude careless responses and misinterpretations from the sample for the particular question in the questionnaire:

- If the respondent has reported costs exceeding the annual turnover – exclude the data for this respondent from the sample for the specific question (scenario)
- If the respondent has reported higher willingness to pay (WTP values than willingness to accept (WTA) or Direct worth values – exclude the data for this respondent from the sample for the specific question (scenario)
- If the annual electricity consumption given does not correspond to the size of the electricity bill for the same year - exclude the data for this respondent from the sample for the specific question (scenario).

SINTEF recommends imputation of missing data about electricity consumption if possible. It can be calculated from the electricity bill for the whole year divided by the tariff (sum of energy cost tariff and network tariff). In cases where electricity consumption is missing both in terms of kWh and in monetary terms, the consumption may be estimated using representative load curves.

It is recommended to perform statistical test on the material to reveal if the real sample is representative for the random samples since lack of responses (low response rates) might give misleading estimates in case of systematic repeal.

Normalization
The individual raw data should be normalized after quality assurance to make them comparable within the different customer groups, using normalization factors as described above. The normalized data are used to calculate arithmetic means of the costs for the various scenarios and for the different customer groups.

Handling outliers and zeroes
SINTEF recommends to treat the zero costs in the material as zero values and not to exclude them from the material except for those zeroes indicating protest answers which should be included in

the logical tests as described in Chapter 1.14. It is therefore important not to substitute missing values by zeroes in the tools used for data analysis of the collected data.

Furthermore SINTEF recommends no censoring of outliers from the material, but to present the whole distribution of the normalized data together with different measures of dispersion such as standard deviation, maximum and minimum values, percentiles etc.

3 CONSIDERATION OF COUNTRY SPECIFIC CHARACTERISTICS IN THE GUIDELINES

The design of customer surveys should be adapted to the country specific characteristics, since some elements need consideration at a national level. Several elements are quite different depending on the country and have to be considered in the design of the survey. In the following it will be noted which elements need considerations and how this can be approached. The elements are:

- Objective of the cost estimation survey for continuity of supply and voltage disturbances respectively
- Worst case scenarios and use of electricity
- Method of conduction and expected response rates
- Choice of customer groups and standard industrial classification
- Choice of interruption scenarios and voltage disturbance phenomena
- Data available for the normalization factor(s).

Objective of the cost estimation survey
The objective of the survey is highly country specific regarding for which applications the cost data should be used. This discussion should be made at national level.

Worst case scenarios
The worst case scenario is different for each customer group and also country specific. It has to be analyzed when the different customers are most dependent on electricity supply. This can be done by studying the power demand curves of the customers, if one accepts the assumption that electricity consumption and costs are directly related. Another approach is to analyze the activity pattern of the customers, for example when they are producing most (Industry) or when they usually want to watch TV (Households). If the information needed for estimating the electricity demand curve or the activity pattern of a customer group is not available, the worst case scenarios has to be identified directly with the customers. A focus group is an adequate method to do so.

Method of conduction (response rates and sample size)
The response rate and therefore the needed sample size for different conduction methods vary from country to country depending on the cultural background. In common, it can be assumed that response rates for methods with no personal interaction are higher in Northern European countries than in the Southern European countries. The state of the art in part B of the report presents response rates for different countries and customer groups of recent cost estimation studies. These numbers can be used as a starting point for estimating the response rates. In addition, different conduction methods and corresponding response rates can be tested in the pilot study.

Choice of customer groups and standard industrial classification
As explained earlier the customer groups can be defined differently depending on the needs of the national survey. In common, the customer groups should represent the customers with a significant contribution to the economic activities and in addition the households. This has to be assessed country specifically. For example, the agricultural sector can have a significant

importance in terms of employees or contribution to the gross domestic product in some countries. Then this sector should be treated as an independent customer group. The same considerations can be done for other customer groups. The recommendations in the guidelines are furthermore based on the statistical classification of the European Community. A national standard industrial classification should be used, if important information and data are only available with the national classification.

Choice of interruption scenarios and voltage disturbance phenomena
SINTEF recommends describing a reference scenario with a worst case timing when the consequences are expected to be highest as described above. Which interruption scenarios and voltage disturbance scenarios are most important on a national level can be determined studying the national interruption statistics, for instance the most frequent interruption durations, as well as voltage quality statistics when available. Voltage dips will probably be the most important voltage disturbance nationally for most countries. The second most important voltage disturbance in many countries is probably transient overvoltages from lightning strikes and switching operations. In some countries harmonic voltages may also be very important.

Data available for the normalization factor(s)
If annual electricity consumption is to be used for normalization this will be collected through the questionnaire (recommended by default). Choice of for instance maximum load or load at reference time of the survey requires that either load measurements (hourly values) are available for the individual respondents to produce load curves or that typical (general) load curves are available for different customer groups. Load curves are also necessary for eventual imputation (estimation) of annual electricity consumption where missing in the surveyed data.

PART B

STATE OF THE ART OF SURVEY METHODOLOGY

The state of the art report is mainly based on Bowitz et al. (2010) and the sources used in that report. In addition, some new surveys were included as well as economic literature to provide a more comprehensive insight into the survey methods and how to design a questionnaire. The articles used for the state of the art report can be classified as in Table 9. Part B contains the state of the art according to this literature reviewed.

Reports categorized into cost estimation are studies with the aim to estimate costs of interruptions and voltage disturbances for different customer groups. Methodology studies focus on the methods used in cost estimation studies, and often how these methods can be improved to get more reliable data or how the collected data can be used most efficiently to build representative cost models. These studies are not necessarily restricted to outage cost estimation, and are normally more general in their character. Meta-analyses use cost estimates from other cost estimation studies and analyze these data further. Literature review articles give an overview of cost estimation studies and the state of the art of methods. Articles in the category long term cost drivers focus on the development of costs due to quality of supply problems over longer time periods and the main drivers for that development. Infrastructure article include to a given extent the costs if infrastructure customers are affected by quality of supply problems.

The state of the art report is structured in different chapters. The first chapter deals with the different methods to collect data from the customers to estimate the costs of quality of supply problems. The main characteristics of the methods are presented and which methods can be used to estimate what kind of costs. The second chapter explains how questionnaires are designed and conducted. The third chapter outlines how cost functions and cost estimates can be obtained from the collected data. In addition, the last chapter presents results of cost estimates from recent cost estimation studies.

Table 9: Overview state of the art literature

	Cost estimation studies		Theory and analysis			Special issues	
	Interruption	Voltage disturbance	Methodology studies	Meta-analysis	Literature review	Long term cost drivers	Infrastucture
Accent (2008)	x						
Adamowicz and Deshazo (2006)			x				
Adenikinju (2003)	x						
Alvehag and Söder (2007)			x				
Anderson et al. (2007)	x						
Arrow et al. (1993)			x				
Beenstock et al. (1998)	x		x				
Bertazzi et al. (2005)	x						
Billinton, R. (2001)					x		
Blass et al. (2008)	x		x				
Bose et al. (2006)	x						
Bowitz et al. (2010)					x		
Baarsma and Hop (2009)	x						
Carlsson and Martinsson (2004)	x						
Carlsson and Martinsson (2006)	x						
Carlsson and Martinsson (2008a)	x						
Carlsson and Martinsson (2008b)			x				
Caves et al. (1990)					x		
Concept Economics (2008)	x				x		
Costantini and Gracceva (2004)							x
CRA International (2008)	x						
de Nooij et al. (2007)	x						
Delfanti et al. (2010)		x					
EPPO (2001)	x	x					
Eto et al. (2001)					x		
Frost et al. (2004)							x
Hradilek and Prokop (2007)	x						
Kateregga (2009)	x						
Kivikko et al. (2008)			x				
Kjølle et al. (2008)	x	x					
LaCommare and Eto (2004)				x			
LaCommare and Eto (2006)				x			
Lawton et al. (2003)	x			x			
Layton and Moeltner (2005)	x	(x)					
Mili et al. (2004)	x						x
Moeltner and Layton (2002)			x				
Moore et al. (2006)	x						x
Morrison and Nalder (2009)	x	x					
Pearce et al. (2006)			x				
Raesaar et al. (2005)	x						
Samdal et al. (2006)			x				
Silvast et al. (2006)	x						
Suifeng et al. (2007)	x						
Sullivan and Sheehan (2000)						x	
Sullivan et al. (2009)				x			
Sun et al. (2009)	x						
Svensk Energi (2004)	x						
Targosz and Manson (2007)	x	x					
Tiedemann (2004)	x						
Tol (2007)	x	x					
Vencorp (2009)						x	
Yamashita et al.(2008)	x						

x – report covers the topic

(x) – report covers the topic to some extent

1 METHODS FOR COST ESTIMATION OF QUALITY OF SUPPLY PROBLEMS

In this chapter we will go through the most relevant methods to value quality problems in electricity supply and discuss their advantages and disadvantages. The description of the methods and their usefulness towards quality of supply methods are based on the experiences of conducted surveys and general literature on available techniques to value a service. An ideal valuation method should:

- give an estimate that covers total socio-economic costs (not only customer costs and not only monetary costs)
- give estimates with a small margin of error or uncertainty, and with little possibility for manipulation and strategic assessments
- not be too expensive or methodologically complicated to implement.

The recommendations may differ between customer groups and quality problems (interruption or voltage disturbance), depending on the different importance of the cost components, access to data, customers' competence and incentives.

1.1 DIFFERENT TYPES OF VALUATION METHODS

Cost estimation methods for both interruptions and voltage disturbances may be categorized in different ways. One is the Bottom-Up versus Top-Down approach. Most studies take a Bottom-up approach, implying that they collect cost data on a detailed level (for example through surveys) and then add up. To uncover a cost function by specifying how the cost depends on a range of explanatory variables, a Bottom-Up approach is probably necessary. Methods based on a Top-Down approach make approximations based on available data on a macro-economic level, the so-called "production-function method" is an example of this.

Furthermore, cost investigations may be an ex-post analysis of real interruption events or based on hypothetical scenarios. Case studies of interruptions, studying price changes or asking people what their costs were, are often thought to give more certain and realistic cost numbers, but on the other hand the results are not necessarily transferable to other situations.

A commonly used categorization is between stated preference methods and revealed preference methods. Stated preference methods are based on asking individuals to elicit their intended future behaviour in constructed markets. This is the most common approach to estimate interruption costs. Revealed preference methods base the cost estimates on the observation of real choices in the market by the customer. Examples are investment in back-up generation or other mitigation approaches, such as insurance premiums for utility service interruption. Both methods are based on economic theory and the assumption that people are utility-maximizing.

Another dimension is direct versus indirect methods. Direct methods focus explicitly on costs (or willingness to pay or willingness to accept), either by surveys or by studying markets. Indirect methods uncover preferences and priorities (again by surveys or by studying markets) without focusing explicitly on the cost of quality problem. The cost must be estimated in a separate operation through the use of econometric models.

Based on the literature review, the cost estimation methods are categorized in the following manner. These methods are described in more detail in the following sections.

- Survey methods
  - Direct Worth
  - Stated preference methods
    - Contingent valuation (direct measurement of willingness to pay or willingness to accept)
    - Conjoint analysis (choice methods, indirect measurement, willingness to pay or willingness to accept is estimated by the researcher, based on the respondents' ranking, rating or choice between scenarios)
    - Preparatory action method
- Market based methods (revealed preference methods).
  - Preventative cost method
  - Different electricity tariffs
  - "Proxy methods" based on market prices
- Production-function methods
- Other methods
  - Meta-analysis
  - Case studies
  - Expert groups.

In the following the main methods will be presented with short examples. These methods are widely used for cost estimation of interruptions and only to a given extent for cost estimation of voltage disturbances. Therefore the examples are based on interruptions. But generally, all methods are also applicable for voltage disturbances.

1.2 ADVANTAGES AND DISADVANTAGES OF DIFFERENT METHODS

1.2.1 Survey methods (Direct worth and stated preference)

Direct worth method

Description

The Direct worth method is commonly used to estimate the monetary cost of quality problems in electricity supply and the data collection is based on surveys. Customers are asked to estimate the expenses which incur due to a hypothetical or experienced quality of supply problem. Usually several scenarios are presented to the customer, and the customer has to specify the economic costs according to predefined cost categories.

Advantages	*Disadvantages*
• Customers normally are the best to know their own costs. This should in principle lead to good and precise estimates of their monetary costs. The reliability of the estimates derived from this method is increased if the interviewer is involved in the estimation process to avoid calculation errors. • Spill-over costs on clients, suppliers etc. may also be estimated if such questions are included in the survey (however estimates will be highly uncertain)	• Only monetary costs are covered. Non-monetary costs could be a considerable part of total customer cost, especially for households. • Often, a large effort is needed from the respondent to answer a Direct Worth survey, as the questions are usually quite demanding. The complexity of the questions might cause the accuracy of the answers to suffer, especially if the study includes many scenarios. • Strategic responses may occur. The questions are only hypothetical; no payment is actually being made. If the respondent knows that the results are to be used in the future regulation of the power sector (for example to set compensation rates), it may lead him/her to overstate his costs.

Example

Assume that an electricity interruption occurs at 10 am on a Thursday in January without advance warning, lasting for 1 hour. Estimate the cost of this interruption.

Lost production (minus savings):
Costs for making up production (overtime, etc.):
Costs for delayed delivery (fines, etc.):
Damage to raw materials and finished products:
Damage to equipment:

Sum of all costs [€]:

In general it can be concluded that the Direct worth method is well suited for analyzing commercial and industrial customers. For these customers the monetary costs is the dominant cost component. The method may also be used for Households, to cover the monetary part of customer costs, but it is important to test the questionnaire and survey design to make sure it is accommodated to respondents' level of understanding. For example, instead of using technical terminology, it may be better to describe the effects of the different phenomena (lights flickering etc). This is assumed to be especially important when asking about voltage disturbances.

Contingent valuation

Description Contingent valuation has for long been the dominant stated preference method. In Contingent Valuation studies the respondent is presented with a hypothetical or experienced scenario of an interruption or other quality of supply problem, and asked for the willingness to pay for avoiding it or willingness to accept compensation, to be indifferent to the welfare losses in the scenario. There must be a detailed description of the scenarios, and the scenarios must be realistic and accepted by the respondent.	
Advantages	*Disadvantages*
• Contingent Valuation studies focus explicitly on the purpose of the study; to get an estimate of total costs for different parties, including non-monetary costs (and if relevant, non-use values). • The questionnaire often includes only one question about the worth. Thus, it is less demanding for the respondent than answering to several cost categories as for example in Direct Worth method.	• The willingness to pay and willingness to accept estimate should be equal, but they differ from each other substantially because of loss aversion of the customers (willingness to pay considerably lower than willingness to accept). • In general the costs and the effort of conducting a survey may be high, especially if the survey is implemented through personal interviews. • As with Direct Worth, there may be problems with strategic answering, since no real payment is being made. • In general, it may be cognitively difficult for people to put a monetary value on services that they are not accustomed to assess in monetary terms. The "auction situation" where buyers state their willingness to pay for something, is not regular in most European countries, where goods are normally presented with given price tags. • There have been problems with "protest answers" (for example people reporting zero willingness to pay even though the interruption/voltage disturbance causes costs).

Examples

Willingness to pay

Assume that hypothetically a reserve power supply is available that could supply the entire company's electricity needs during an interruption. The reserve supply is purchased only for the time actually in use. How much would your company be willing to pay for such a service to maintain power supply during an interruption with the following characteristics and thus avoid the cost of the interruption?

Duration: 2 hour
Season: July
Day of week: working day
Time of day: 6 am
Warning: no advance warning

Willing to pay for the service [€]:

Willingness to accept

Assume that the network company informs you about an interruption, just before the interruption will occur (no time for preventative actions). The company can choose whether it will accept the power interruption and simultaneously receives a financial compensation, or whether the power supply is not switched off and thus the company can produce normally. What is the minimum amount of compensation the company needs to choose to accept a power interruption with the following characteristics?

Duration: 2 hour
Season: July
Day of week: working day
Time of day: 6 am
Warning: no advance warning

The minimum compensation is [€]:

Overall, the Contingent Valuation technique has been the subject of great controversy. Contingent Valuation studies often seem to produce an estimate that contains a large uncertainty. However, many of the criticisms of the technique can be said to be imputable to problems at the survey design and implementation stage rather than to some intrinsic methodological flaw. The Contingent Valuation method has mostly been used for estimating the interruption costs of household customers as non-monetary costs are often important for such customers. The method has also been used for business, in combination with other approaches such as Direct Worth. However, the whole concept of willingness to pay is based on individual utility maximization, and a company as such is not assumed to have any preferences apart from profit maximization.

Conjoint analysis

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Description

Conjoint analysis is another class of stated preference methods that are based on customers expressing their preferences for different hypothetical scenarios. Instead of asking directly for the costs, willingness to pay or willingness to accept for quality problems, customers are asked to select the preferred alternative 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 methods. Conjoint analysis has no long tradition in the quality of supply field, but is used in several studies during the latest years.[11]

The scenarios may be built up by several attributes (time of day, day of week, season, advance notice or not, frequency etc). By including price as one of the attributes of the good, willingness to pay (willingness to accept) can be indirectly recovered from people's choices. Instead of valuing a certain good only once, as is most common in Contingent Valuation studies, respondents are typically presented with a menu of scenarios, where attributes are slightly changed from scenario to scenario, such that preferences for various components or attributes can be examined at a more refined level.

There are different variants of Conjoint Analysis. The most common are choice experiments; others are ranking and rating methods. Ranking implies to order the scenarios from least preferable to most preferable on an ordinal scale. Rating the scenarios using a cardinal rating is sometimes used to obtain more information about the gap between the attractiveness of different scenarios. Choice experiment implies choosing the single most preferred option from a choice set. This is normally easier for a respondent than to rank or rate different alternatives, and this is one of the reasons why choice experiments have become the most attractive method.

</td></tr>
<tr><td>Advantages</td><td>Disadvantages</td></tr>
<tr><td>

- Similar to Contingent valuation this method makes it possible to include non-monetary costs.
- Choosing between alternatives produces less stress among respondents and is considered a more realistic decision situation than expressing willingness to pay directly. It is also probably more difficult for respondents to answer strategically and to exhibit protest behaviour in Conjoint Analysis surveys.
- Many analysts seem to find Conjoint Analysis more reliable than Contingent Valuation for that reason.
- Conjoint Analysis leads automatically to the decomposition of preferences into utilities for separate attributes, which is suitable for power interruptions and voltage disturbances since these have a multidimensional character. We are often not only interested in knowing the cost per interruption, but to estimate costs as functions depending on many attributes.

</td><td>

- Conjoint Analysis typically needs sophisticated econometric models to estimate the costs. This may be quite laborious and the results may also be difficult to explain.
- It might be challenging to set the right value of the price tags in the scenarios.
- Another possible drawback is that people are not explicitly aware of the valuations they make, and this may reduce the reliability of the results. In general, there is a cognitive difficulty associated with multiple, complex choices between bundles of attributes.
- Studies that do not include status quo or a "do nothing" alternative in the choice set, can not be interpreted in standard welfare economic terms. Ranking and rating methods often do not include status quo whereas choice experiments normally does. With rating exercises there is also a problem that ratings are not necessarily comparable across individuals.

</td></tr>
</table>

[11] Conjoint Analysis has been widely used in the market research and transport literature.

Example

The example shows a vignette with a relative price change and where the scenarios has to be rated.

Source: Baarsma and Hopp 2009

Single-outage: Series A, card 1	
Duration of the outage	2 h
Day of the week	Wednesday
Part of the day	In the afternoon (12 p.m. till 6 p.m.)
Season	Summer
Warning in advance	Without warning
Change in electricity bill	5% discount
Rating mark	–

Conjoint Analysis is best suited for household surveys since it includes non-monetary costs. In the recent years cost estimation studies have applied Conjoint analysis mainly for Households, but also for Industry and Commercial customers. It is important to assure that the competence is available in the organization to conduct the cost analysis of the data, before one decides to apply Conjoint analysis.

Preparatory action method

Description

The preparatory action method is a method where the customer is asked to choose from a list of hypothetical actions which reduce the consequences of a certain quality of supply problem. Each action is associated with a given cost. An action can be for example the purchase of candles in households.

Advantages	*Disadvantages*
• Cost estimation is associated with practical actions. • Less cognitive stress for the respondent than in Contingent valuation or Conjoint Analysis.	• It is demanding to design a good list of actions which covers a broad range of costs, and it will probably not be able to include all.

Example

List of possible preparatory actions for households based on CRA 2008

- Light candles or use a torch to provide basic lighting (0.50 €)
- Buy a gas lantern, to provide better lighting (9 €)
- Buy some ice and put it in your refrigerator (2 €)
- Drive to a relative or friend's home (10 €)
- Buy a portable gas stove or barbecue for cooking (19 €)
- Buy a battery backup power supply to allow PC use (30 €)
- Buy a portable kerosene or LPG space heater (30 €)
- Go to restaurant for one meal (50 €)

The preparatory action approach is not widely used in cost estimation studies, but can be a good supplement to other Contingent valuation methods.

1.2.2 Market based methods (revealed preferences)

Economists have developed a range of approaches to estimate the value of non-market goods by market based methods. The most relevant method in this case is the Preventative cost method. In addition to the Preventative cost method, some other less relevant methods are mentioned at the end of the section for the reason of completeness.

Preventative cost method

Description	
The preventative cost method measures expenditures of the customers to prevent or counteract the consequences of interruptions and voltage disturbances. Examples are physical equipment such as emergency power supply, as well as financial insurances. The value of such purchases can be seen as an estimate for the costs of a quality of supply problem that they seek to avoid. The preventative cost method should not be confused with the preparatory action method even if they are related. The main difference is that the preparatory action method asks for actions which are not implemented at the customer whereas the preventative cost method asks for the cost of preventative equipment which already is installed.	
Advantages	*Disadvantages*
• It is normally easy to collect data, since available market data can be used. • Data shows real market behaviour, not hypothetical statements. • It is worth noticing that these studies are a way to capture the option value of electricity.	• Spill-over costs are not included. • The preventative cost method will provide a bound for the customer costs, not a precise estimate. We only know that the customer costs are at least as high as the backup costs. For customers who have not chosen to install a backup solution, the backup costs may be seen as an upper bound. • It is difficult to calculate the actual costs of emergency power since it does not only depend on the installation costs, but also on the operation costs and the expected utilization time. • Also, customers will often try to mitigate the problem by none-market means as well. An example could be spending time checking the electronic equipment daily. Such non-monetary costs are not captured in this approach.
Example What are the investment cost for your backup solutions (€): ___________________ What are the operational costs for these backup solutions in one year (€): _______________	

The preventative cost method is rarely used to value quality of electricity supply. One exception is in developing countries where there is very low reliability and therefore a high use of preventative measures such as backup systems. Also, in industries where the reliability of electricity is highly critical it would be interesting to perform case studies.

Different electricity tariffs

In an ideal world where electricity customers were faced with different tariff options depending on the guaranteed quality of supply, the willingness to pay for the quality could easily be estimated. In reality, however, such tariff options are normally not available. But this method could become more relevant in future electricity networks and more liberalised markets, if more individual electricity tariffs will be established.

"Proxy methods" based on market prices

There are some market prices that could be used as – highly inaccurate – approximations of the costs of quality of supply problems. The production-function method described below is an example of a proxy method. Others, less frequently used because of their simplistic and unrealistic assumptions, are:

- The cost of electricity, taken as an estimate of customers' minimum willingness to pay for reliability
- The depreciation rates of electrical equipment: taken as an estimate for interruption costs of households.
- Stock prices of firms at the financial markets. This method observes the development of stock prices of companies before and after a real interruption event.

1.2.3 Production function method

Production function methods can be divided into the general Production function approach and more advanced models; the Input-output models.

Production function approach

Description	
The Production function approach is based on electricity being an input to production, which means that unserved electricity leads to a loss of value creation. The method takes a macroeconomic approach and is based on somewhat simplistic assumptions. It assumes that a firm's value added is directly proportional to its consumption of electricity. The cost of an interruption or other quality problems is then measured by the assumed lost production (or increased costs of production). For the household sector, it is assumed that electricity is needed for "house production" and other leisure activities, so an interruption will lead to lost leisure time. Leisure time is normally valued according to their wage rates (net of all taxes)[12].	
Advantages	*Disadvantages*
• Data is easily available. The method uses quantitative statistical information published by the national statistical bureau.	• Only the assumed effects of lost production is included, not the value of any damage to equipment, extra overtime, and costs of delayed deliveries etc. or non-monetary costs due to inconvenience. The applicability of this method should be assessed on an industry-to-industry basis. It is especially problematic in the household sector. • Usually the method is based on annual data, which may not be appropriate for analysing shorter interruptions with durations of a couple of hours or voltage disturbances. In many cases it is probably easy to recover lost production, and households may postpone electricity-consuming activities without great cost. • In practice the estimate given by the production-function approach may overstate or understate real costs. It is assumed to give a rather uncertain estimate.

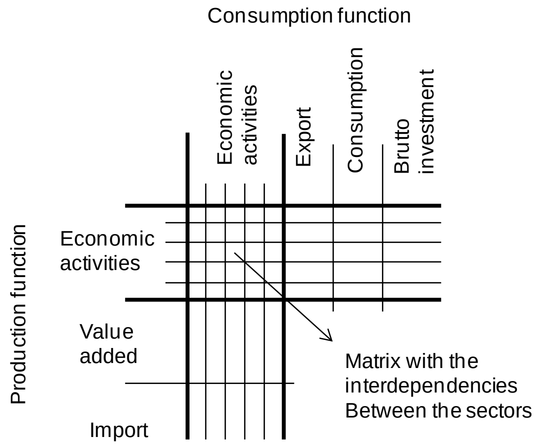
In addition to the more simple Production function approaches there are also more advanced models, known as Input-output models.

[12] If an individual can choose his working hours freely in the labour market, he will be indifferent about his use of time in the baseline scenario. Time spent on work is there valued as wage including all taxes, whereas leisure time is valued as wage excluding taxes (the individual's net income). One could also use stated preference methods to estimate the value of leisure time, for example Conjoint Analysis are often used in transport economics to reveal what people are willing to pay to save travel time.

Input-output model

Description

Input-output models are based on the Production function approach, but include in addition interdependencies between sectors in the economy. This procedure makes it possible to estimate spill-over effects resulting in costs in other sectors of the economy than the sector experiencing the interruption. An Input-output model represents the economy with a matrix built up of the individual production and consumption functions of the different sectors including households. The following figure shows these interrelations. The economic activities represent the different sectors that are purchasing input goods from other sectors in the region/country or importing goods. These relations give the production function for each sector. The different sectors are selling their goods again to other sectors. Alternatively the goods are exported or consumed. If the production of one or several sectors is reduced due to interruptions, the Input-Output model can show the spill-over effects to other sectors based on two effects. The sectors with lower production will purchase fewer goods from other sectors, but also sectors dependent on deliveries from the sectors with lower production have in theory to reduce their production. These kinds of spill-over effects can be captured with the Input-Output model.



Advantages	*Disadvantages*
• Data is easily available. The method uses quantitative statistical information published by the national statistical bureau. • Possible to estimate spill-over effects in the form of lost production in the rest of the economy.	• Only the assumed effects of lost production is included, not the value of any damage to equipment, extra overtime, and costs of delayed deliveries etc. or non-monetary costs due to inconvenience. The applicability of this method should be assessed on an industry-to-industry basis. It is especially problematic in the household sector. • Usually the method is based on annual data, which may not be appropriate for analysing shorter interruptions with durations of a couple of hours or voltage disturbances. In many cases it is probably easy to recover lost production, and households may postpone electricity-consuming activities without great cost. • In practice the estimate given by the production-function approach may overstate or understate real costs. It is assumed to give a rather uncertain estimate.

1.2.4 Other methods

In addition to the main groups of valuation methods for costs of interruptions and voltage disturbances, we briefly mention three other methods that can be used to value quality of electricity supply.

Meta-analysis
Meta-analysis is a process of "borrowing" values estimated from other studies. This method has a potential for saving considerable time and effort. The possibility for benefit transfer is one of the "goals" of any valuation method. However, it is important to consider the transferability in time, between different contexts and between countries. Especially one should be sceptical to the transfer of unit values (for example an estimate of willingness to pay per interruption or per kWh) because it is very context dependent. Transfer of a cost function may be more appealing. Some studies perform regression analysis based on several earlier studies to make a more general model. However one should be careful transferring data from other studies (performed in other countries) as the use of electricity, the cost levels, markets and customer segments may be different. Special care should be given if the cost estimates are normalized as the normalization factors may be considerably different.

Case studies
The term case study can be defined in two ways. First, case studies are ex post investigations of the costs of large blackouts or interruptions/voltage disturbances at the customer level. However, the costs of actual events may be analyzed with any of the other methods described in this report. An important advantage with that kind of case studies is that they are based on real customer experience and not hypothetical scenarios. The main challenge is that case studies are not necessarily representative for other quality problems, at other times and in other geographical regions. Usually these studies are conducted for large blackouts, often under extreme weather conditions, and the results cannot be applied to small interruptions and individual customers.

Secondly, a case study can also be understood as the intensive analysis of one or several cases in question. These cases are usually typical customers who can represent a large customer group or customers which have so complex consequences that the costs of quality of supply problems have to be assessed on a case-to-case basis. These case studies can be based on both real experience and hypothetical scenarios. The case based approach recommended in the guidelines refers to this definition of case studies.

Expert panels
Certain subjects are not very well known to the general population, and should therefore not be valued by survey methods. Different methods are developed that are based on experts' preferences. But as long as these experts are not representative of the population, the use of these preferences is however not in line with welfare theory.

1.3 METHOD CHARACTERISTICS IN RELATION TO SPECIAL ASPECTS

This section will look closer at the characteristics of the different methods towards special topics of interest as extreme and strategic answers, accountability and uncertainties of the cost estimate, and methods which can be used to estimate the total socio-economic costs.

1.3.1 Extreme and strategic answers and loss aversion

When measuring costs with survey methods, it is important to be aware of the risk that respondents are not presenting their "true" values. Several reasons can be mentioned.

- Strategic answers: Some respondents will deliberately overstate their costs. This may be the case if they expect that the results are used in the future regulation of the power sector. Understating the cost may also happen, for example if people believe that the results will be used to differentiate their price of electricity.
- Protest answers: Another risk is that respondents refuse to "play the game" and protest to some aspect of the contingent market described in the scenario. Typically they will protest to the payment mechanism (e.g. higher energy prices or taxes). A respondent who finds it unreasonable and unfair to pay more for a service that he "has already paid for" or to pay for resolving a problem that "is someone else's fault", might demonstrate this by responding a willingness to pay of zero.[13]
- Loss aversion: Another challenge is that people are often risk averse, and therefore have a high willingness to pay to avoid deterioration in welfare, but not so high for improvements. This asymmetry must be taken into account when creating the questionnaire.

These problems are especially relevant for the survey methods, where only hypothetical questions are posed and therefore of particular relevance for Contingent Valuation studies, and to some degree Direct Worth studies. On the other hand, market based methods, are based on real market observations. But the preventative cost method is also based on asking people, and might to some degree be exposed to the "strategic answer" problem. Strategic answers are relevant for both Direct Worth and all Stated Preference, whereas protest answers are mostly relevant when asking about willingness to pay or willingness to accept as in Contingent Valuation methods. It can also be expected that Conjoint Analysis produces less strategic answers and extreme answers since the design of the choice situation makes it difficult to influence the results directly.

What can be done to avoid these problems? The literature mentions different approaches. Strategic and protest answers may be detected in the form of extreme answers or outliers (either zero or unrealistically high numbers). It is always important to perform quality assurance of the data material before the estimation. Extreme answers may be the result of misprinting, misunderstanding, protest or strategic behaviour – or it may also be representing the true cost for those respondents. It is normally difficult to distinguish between different explanations. However,

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[13] Studies from the environmental sector often show people reporting a very high WTP for goods that are "politically/socially correct", either because of social pressure or to make a political statement. In neither of these cases the stated cost will equal their real willingness to pay.

two important recommendations that can be found in the literature are that you should explicitly allow for a “no-answer” option[14], and you should follow up on extreme answers and ask the respondent about the reason behind his statement[15].

Also, some other advices are mentioned as advantageous in the literature. The use of focus groups and pilots to test the questionnaire design is recommended. Personal interviews are usually recommended, since it allows for detailed explanations of the scenarios, making sure that scenarios are realistic and acceptable. But in practice, personal interviews are not always practicable due to their high costs and the amount of human resources needed. Closed-ended questions are less exposed to extreme answers than open-ended questions. Asking for willingness to pay instead of willingness to accept will also normally reduce the risk of extreme high answers. Protest answers can also partly be revealed by including questions about the customer’s satisfaction with the quality of supply level and the grid company[16].

1.3.2 Accountability and treatment of uncertainties of the cost estimates

It is important that the cost estimates retrieved by surveys are both valid (accountability) and reliable (uncertainties). There should be no uncertainty about what is really measured, and neither about the estimate’s precision and consistency.

Accountability is understood as capability of capturing all relevant elements of “socio-economic cost of quality of supply problems”. This involves private customer costs as well as spill-over costs, monetary and non-monetary costs etc. In addition to costs of actually being exposed to a quality problem, there is the ex ante cost category; the option value[17]. Studies differ in which cost categories they focus on. The following table gives an overview about which methods cover which cost categories.

Table 10: Accountability of different methods

		Direct Worth	Contingent valuation	Conjoint analysis	Preparatory action method	Preventa-tive cost method	"Simple" production function	Input-output model
Private customer costs	Non-monetary		x	x	x	x		
	Monetary	x	x	x	x	x	(x)	(x)
Spill-over costs	Non-monetary							
	Monetary	(x)						(x)
Option value			(x)	(x)		x		

x – Method covers the cost category
(x) – Method covers the cost category, but due to inherent limitations of the method the quality of the cost estimates is limited

14 Respondents who choose the “no-answer” option should be asked to explain their choice. Reasons may for example be: indifference between the alternatives, inability to make a decision without more time and information, preference for some other mechanism, or bored by the survey.
15 Ideally, answers should be followed up by the question "Why did you vote yes/no?" In this way it would be possible to identify respondents stating for example “I refuse to pay any more, it is the grid company’s fault”.
16 See also the more general recommendations for Contingent valuation studies in section 2.3.1.
17 An explanation of option value can be found in Chapter 2.3 Cost terms for describing consequences.

It is important to be aware what cost estimates are needed. Therefore the literature also recommends using several methods to cover all cost categories. The Direct Worth method asks respondents about their monetary costs only. It is therefore most relevant for customer groups and quality problems that primarily involve monetary costs as for example industrial customers.

Stated preference methods may, if questions are correctly posed, cover respondents' total willingness to pay, including their non-monetary costs and if relevant, non-use values. It is therefore an attractive method for estimation of household costs. Note that stated preference studies may also cover option values, if the scenario describes an insurance against quality problems for a certain period, as opposed to the avoidance of a problem that would otherwise happen with certainty. One should be aware of the difference. In practice the choice of scenarios must depend on what the study is going to be used for. This approach is also possible with the preparatory action method. It may cover option values, depending on how the questions are posed. Conjoint Analysis does not capture more cost categories than Contingent Valuation, but has an advantage if the focus is on the multidimensional aspect of quality problems, since it allows for the decomposition into utilities for separate attributes.

Revealed preference methods focuses on monetary costs, and do not capture non-monetary costs. However, if option values are important, there is a possibility to use observations from the insurance market. The preventative cost method focuses particularly on option values and risk aversion.

The production-function approach also focuses on monetary costs, but can not cover costs because of lost equipment. With the Input-output model however, it also estimates spill-over costs in a systematic way. Direct Worth and Stated preferences studies may also include questions about spill-over costs, but the answers will be rather uncertain and there is a risk of double-counting.

Uncertain cost estimates are produced by many of the methods. The following figure gives some examples of the uncertainty and therewith the standard deviation of some costs estimates.

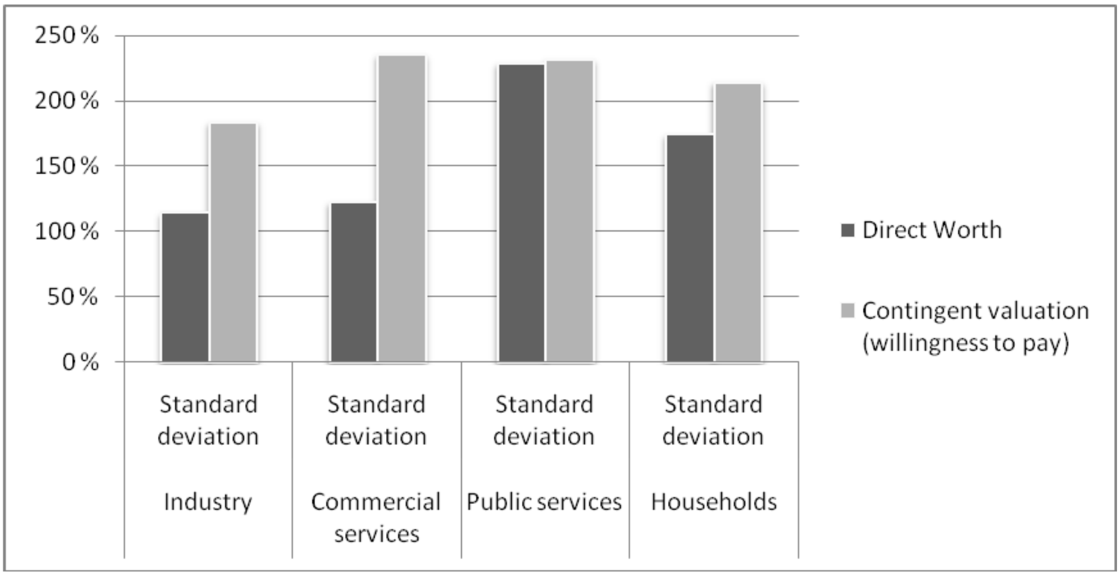

Figure 9: Standard deviation of cost estimates, censored data, 1 hour interruption, NOK/kWh (Source: Kjølle et al. 2008)

Stated preference methods and in detail Contingent Valuation is one of the most commonly used methods, but is also criticized for producing highly uncertain estimates. Extreme and strategic answers are an important aspect of this. Other challenges are respondents' lack of knowledge, and the questions' complexity, that may lead to answers being given arbitrarily. It is not obvious, if the answers of Contingent Valuation or of Conjoint analysis are most uncertain. Probably, it is easier for respondents to give sensible answers in Conjoint analysis, since it resembles a realistic choice situation. But on the other hand, the costs must be estimated indirectly in Conjoint analysis which can introduce new uncertainties. The Direct Worth method and the Preparatory action method are somewhat less exposed to reliability problems since they only involve monetary costs. However, when using predetermined answers one must be careful to include all relevant alternatives. And special care should be taken, if questions about spill-over costs are included.

Two approaches can be utilized to quantify the uncertainty of the cost estimates. The cost estimates can be quality assured by opening for the possibility that respondents can be interviewed after they filled out the questionnaire. By doing so, biases in their responses can be identified and the uncertainty of different methods can be quantified. Another approach is to perform experiments in a laboratory environment to identify the real costs of the respondents. A game can be introduced to reassemble real market choices and based on the decision of the customers in that experiment the uncertainties of the estimates done in the survey could be assessed. Both approaches are demanding and should rather be regarded as research towards the improvement of survey methods.

Revealed preference methods produce cost estimates based on real market behaviour, and are therefore more certain than answers to hypothetical questions. On the other hand, these methods often capture only a part of the costs. The production function method is an example of this fact. It gives precise estimates, based on official statistics, however it measures only one type of cost: lost production, and it measures spill-over costs under the unrealistic assumption that no adaptation can be made.

1.3.3 Methods for estimating total socio-economic costs

Most of the methods focus exclusively on private customer costs. The only method that is really designed to include spill-over costs is the production-function approach – when extended to include interdependencies between sectors in the economy (i.e. Input-output models). Several studies have used such models and found that the spill-over costs from interruptions may be significant. It is also interesting that the total effects may in some cases be higher in sectors that are indirectly affected than in the sectors that experience an interruption in the first place.

If the production-function approach is not chosen, however, it is less obvious how to quantify spill-over effects. Probably the analysis will have to be partly a qualitative assessment of costs. There is in principle no reason for a survey to be limited to customers. One could for example implement a survey on the whole population in a region, and ask respondents about their costs in several roles (customer, client or supplier to other companies dependent on electricity, commuter etc). One could also ask about people's acceptance for reliability problems in public sectors and critical infrastructure (e.g. "longest acceptable interruption duration" for different facilities). This would however be a very complex analysis (one must for example correct for transfer effects to find net effects to society) and probably very expensive to implement. A more realistic approach is to include questions about customers' opinions on likely spill-over effects in the customer survey. Customers in the Infrastructure group should be included. As the answers may be somewhat subjective and possibly strategic, however, the results must be complemented by other, more qualitative analyses.

Critical infrastructure and sectors with responsibility for the population's health and safety have very often invested heavily in backup solutions. It is therefore possible to use the costs of these systems as a minimum estimate of willingness to pay to avoid problems with the quality of supply of electricity (revealed preference method). However, a complicating issue is that the reliability level of critical infrastructure is normally not the result of a cost-benefit trade-off, but often a political decision. In addition, backup solutions are only designed to last for a minimum duration of time and cannot replace the main power supply. Therefore this approach has to be seen with some criticism.

A more profound problem may be that our knowledge about the interdependencies between critical infrastructure sectors and the rest of society, as for example the value chains, is rather limited. Perhaps is a hospital's vulnerability to the loss of electricity supply less of a problem than the vulnerability towards interrupted deliveries from other sectors – that are dependent on electricity. There is a need for more knowledge about these dependencies, since Input-output models are not able to cover such complex dependencies.

1.4 TRIANGULATION OF METHODS

Even within the same survey, more than one method may be included. It is for example rather common to include questions about Direct Worth as well as willingness to pay. Another advantage of this combination is that some questions about monetary costs (Direct Worth) at the beginning of the questionnaire may be a good starting point for the respondent's assessment of his willingness to pay. It is otherwise often difficult to estimate one's willingness to pay "out of the blue". Another advantage is that the triangulation of several methods gives a range of cost estimates, and even if it is complicated to come up with one good cost value, it is possible to say that the real costs have to lie in this range.

Cost estimations which are calculated with the preventative cost method give a lower and upper bound for the possible range of the private customer costs. The lower bound is defined by the costs of for example a backup system or insurance if a customer has decided to take such measures. On the contrary the upper bound of the costs could be defined by the costs of the most cost effective preventative measures that a customer has chosen not to undertake. Preventative measures reduce the costs and consequences of quality supply problems. But the goal of such a survey is to find the actual socio-economic costs and not the theoretical costs when no customer has installed backup. Therefore this cost reduction has not to be considered. The willingness to pay estimates from stated preference methods should be at least as high as the costs of preventative measures, but nevertheless will tend to underestimate the real costs if customers either protest or understate how much they are willing to pay (loss aversion and strategic answering). On the other hand cost estimates based on surveys asking for the willingness to accept usually overestimate the costs since customers tend to overstate the amount of compensation they need as a part of strategic answering and also loss aversion. The Direct Worth method should deliver cost estimates no higher than willingness to pay or to accept, because the method disregards non-monetary costs. For customers where all or most effects results in monetary costs, such as industry and commercial firms, the method should be quite accurate. However in actual studies which include both the Direct worth method and Contingent valuation or Conjoint analysis, the Direct worth method is found to deliver higher cost estimates than the willingness to pay and sometimes even willingness to accept figures. This can be explained partly due to strategic answering, which is easier for Direct Worth questions and risk aversion in the willingness to pay answers.

1.5 APPLICATION OF DIFFERENT METHODS IN RECENT STUDIES

The following table gives an overview about recent cost estimation studies and the methods they used to assess the cost of interruption and voltage disturbances.

Table 11: Former cost surveys and methods applied

Country	Direct worth	Contingent valuation	Conjoint analysis	Preparatory action method	Preventative	"Simple" production	Input-Output analysis	Proxy methods	Source
Australia	firms, pub			house					CRA International (2008)
Australia			firms						Morrison and Nalder (2009)
Canada	FIRMS	FIRMS							Tiedemann (2004)
China						firms			Suifeng et al. (2007)
China						firms			Sun et al. (2009)
Czech republic	*large ind*								Hradilek and Prokop (2007)
Europe	*large firms*								Targosz and Manson (2007)
Estonia	HOUSE, firms	HOUSE							Raesaar et al. 2005
Finland	all	house							Silvast et al. (2006)
India	IND	IND			IND				Bose et al. (2006)
Ireland						house, firms			Tol (2007)
Israel			house						Blass et al. (2008)
Israel		house	house						Beenstock et al. (1998)
Italy	FIRMS	FIRMS, house							Bertazzi, A. et al.(2005)
Italy	*large ind*				*large ind*				Delfanti et al. (2010)
Netherlands			house, firms						Baarsma, Barbara E.; Hop, J. Peter (2009)
Netherlands						all			de Nooij et al. (2007)
New Zealand	*large ind*	*large ind*	house, firms						Concept Economics (2008)
Nigeria					ind				Adenikinju, Adeola F. (2003)
Norway	ALL	ALL		ALL					Kjølle et al. (2008)
Sweden	firms, large ind	house							Svensk Energi (2004)
Sweden	firms, pub, large ind	house							Carlsson and Martinsson (2004), Carlsson and Martinsson (2006)
Sweden			house						Carlsson and Martinsson (2008a)
Thailand	all?	all?		all?					EPPO (2001)
Uganda		house							Kateregga (2009)
UK			house, ind						Accent (2008)
USA							*all*		Anderson et al. (2007)
USA		house							Layton and Moeltner (2005)
USA							all		Moore et al. (2006)
USA	firms	house							Lawton et al. (2003)
USA							all		Mili et al. (2004)
USA, Canada, Italy, Europe								firms	Yamashita et al. (2008)

large	Large customers
ind	Industry
firms	Industry and Commercial services
gov	Public services
house	Households
all	All customers
all?	All customers considered, but method not specified explicitly in the source
CAPITAL	Method triangulation
Normal	No case study
Cursive	Case study
	Interruption
	Voltage disturbance
	Interruption and voltage disturbance

As presented in the table, the most common methods for cost estimation of interruptions are Direct worth and Contingent valuation. Most of the surveys were conducted with these methods. But also other approaches were applied in recent studies. Figure 10 gives an overview about the methods applied.

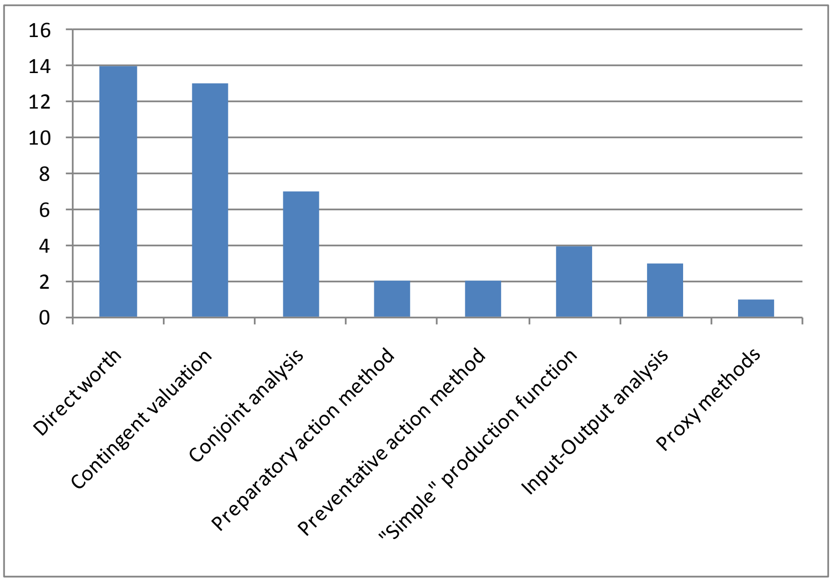

Figure 10: Methods applied in recent cost estimation studies due to interruptions

Some methods are better suited for some customer groups. The following pie charts show which methods are mostly applied for the customer groups Households, Industry, and Commercial services. The Input-output analysis was not considered in the charts, since this approach has to be applied to all customer groups by definition.

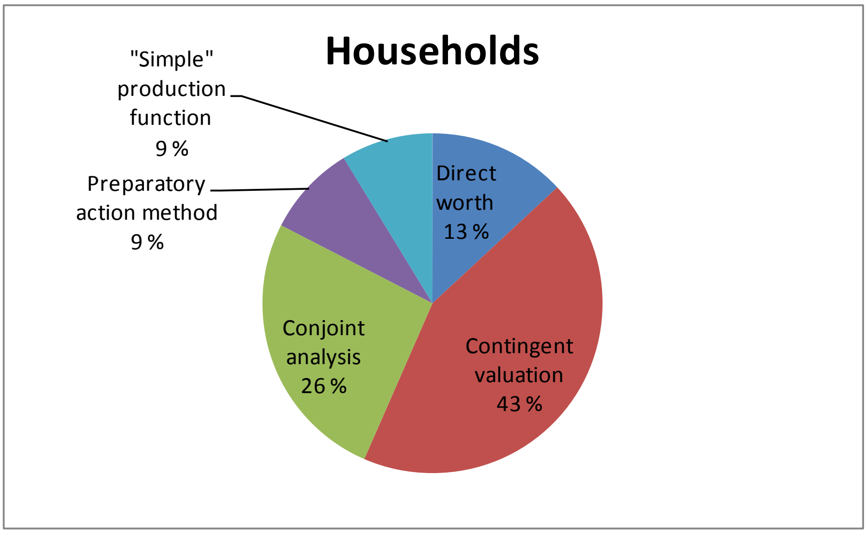

Figure 11: Applied methods for Households

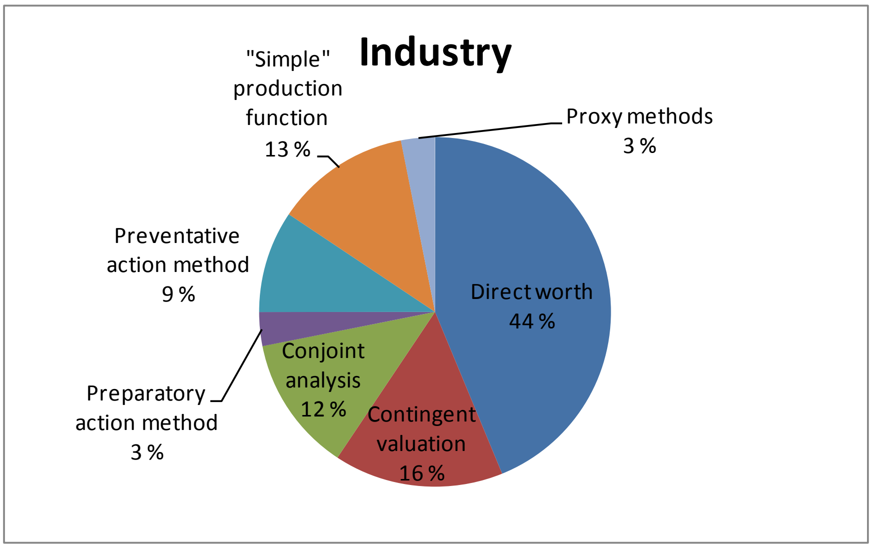

Figure 12: Applied methods for Industry

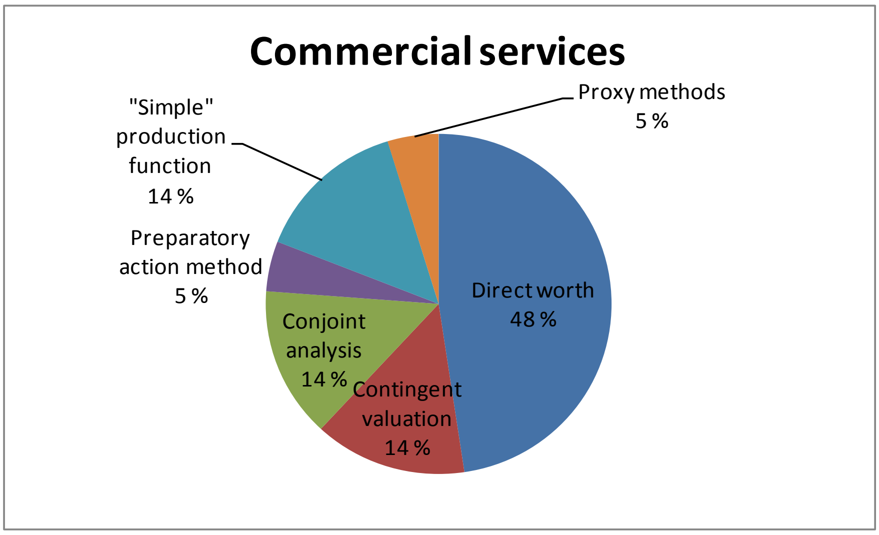

Figure 13: Applied methods for Commercial services

Contingent valuation and Conjoint analysis are the dominating methods for Households, whereas Direct worth is dominating for Industry and Commercial services.

Most of the cost estimation studies are focusing on interruptions and not on voltage disturbances. But several studies included voltage-related problems in their interruption surveys. Only one cost estimation study focused exclusively on voltage disturbances. Figure 14 shows how many of the cost estimation studies have focused on interruptions, voltage disturbances or both.

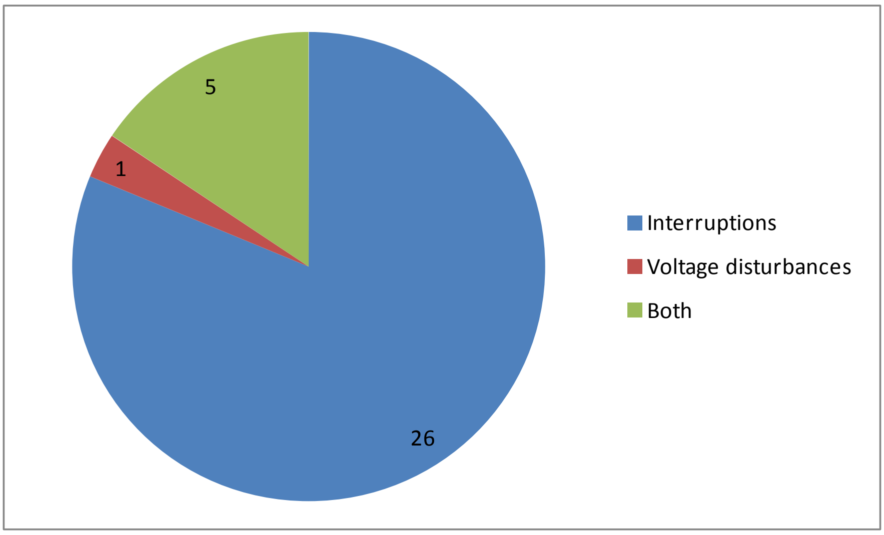

Figure 14: Focus of the cost estimation studies

Various methods were applied in the cost estimation studies which included voltage disturbances. Several studies included voltage disturbances as very short interruptions and used Direct worth or Contingent valuation questions to estimate the costs. In addition, one study applied the Production function approach. The Italian cost estimation study which focused exclusively on voltage disturbances chose a quite unique approach. They used journal of events and measurement data of the voltage quality to assess the costs of voltage disturbances. The company in question had to write a journal where they logged the consequences of experienced voltage disturbances. These data could then be combined with the measurement data to identify what type of voltage disturbances have led to these consequences.

2 DESIGN AND CONDUCTION OF QUESTIONNAIRE

As concluded earlier, questionnaire based survey methods play a decisive role for estimating the cost of interruptions and voltage disturbances. These methods are mostly used for Households, Commercial services, Public services, and Industry. This section will focus on how good questionnaires are designed and conducted.

2.1 CUSTOMER CHARACTERISTICS TO BE CONSIDERED

All questionnaires include questions to register the specific customer characteristics which have an influence on the cost estimate. For Households that can be for example income, education, the number of persons in the household, the size of the flat and the electricity consumption. The costs of interruptions in Households are primarily dependent on whether someone is at home at the time of the interruption or not. Therefore a question in the survey should clarify if the respondent is usually home during the interruption. Other important characteristics are if the household has a sickbed resident, who uses medical equipment or if it has a home business. Medical equipment or computers could be affected by voltage disturbances.

Industrial customers and Commercial services (and partly Public services) are asked for number of employees, annual sales, business type and often the categorization of the company into the specific sector code of the corresponding statistical bureau. In addition, annual electricity consumption and also the individual demand profile (day, week, month and year) are of interest. In addition, it can be asked for the number and type of customers to gain more understanding of possible spill-over effects to the rest of the society.

Other important characteristics for all customers are the region, customer satisfaction and perception of quality of supply, experience with interruptions and voltage disturbances, and backup systems.

Region
The region where the customer is located is of interest from two points of view. First the population density of the region can have an effect on the cost estimate and should be divided at least into urban and rural. Secondly the regional climate can explain the electricity use for heating (if electrical) and cooling. It can be expected that regions with more extreme climate as strong winters or hot summers have higher consequences of interruptions than regions with moderate climate.

Customer satisfaction and perception of reliability
Customer satisfaction and how a customer perceives the quality of electricity supply is also relevant information in a cost estimation study. This information can for example help to understand if a customer tends to give extreme or strategic answers. A displeased customer should tend more to overestimate the costs as well as pleased customers could tend to underestimate them.

Customer experience with interruptions and voltage disturbances
Experiences of the customer with low quality of supply should help the respondent to estimate the costs of such an event. But this can also introduce bias into the estimate since the experience is connected to special events, which can lead to anchoring effects if other hypothetical scenarios than the experienced has to be valuated. The anchoring effect describes the tendency of people to adjust their cost estimates to a reference point, here the experienced scenario. If the costs of the experienced event were high, the respondent will probably overestimate the cost of other scenarios since he/she starts with the experienced costs (the anchor) and makes adjustments to come up with a new cost estimate for the presented scenario. This effect is also valid for the opposite case of low costs due to an experienced quality of supply problem. It is important to include questions about the experience in the questionnaire to allow for analysis of the data for these effects.

Backup systems
Backup systems as well as insurances against the consequences of an interruption or voltage disturbance reduce the cost estimate directly. Therefore it is of importance to gather information about the presence of backup systems and other measures to reduce the effects of quality of supply problems. In addition, it should be clarified if the backup systems can sustain full operations or only parts of it. The costs of the backup systems are usually not included in the cost estimate since the surveys try to give actual cost picture of quality of supply problems including the installed backup solutions.

2.2 DESCRIPTION AND SELECTION OF SUITABLE SCENARIOS

This chapter will present which attributes are usually included in different scenarios for interruptions and voltage disturbances. In addition, worst case scenarios are included often in the surveys to find an upper bound of costs.

2.2.1 Scenario attributes

Each survey uses hypothetical scenarios or quality supply events, where the respondent has to valuate the cost. Such an event can be described with several attributes which have an influence on the cost estimate. This section gives a short overview of attributes which can be used to describe either an interruption or a voltage disturbance event. The time and the frequency of such events are important attributes for both; interruptions and voltage disturbances.

Time
The time of occurrence of a quality supply event is a crucial attribute for the cost estimate, and has to be included in all cost surveys. Time is usually defined by season, day of the week and time of day. The cost estimates do not depend on time as such but on underlying factors which vary by time. These factors can for example be outside temperature as underlying factor for the season, outside light conditions for time of day and usual activities for the day of the week and time of day.

Frequency
The frequency of interruptions and voltage disturbances can have an effect on the cost estimate per event. But even so, this attribute is not always included in the questionnaires of former quality of supply surveys. Frequency can be included by defining scenarios with a specific amount of interruptions/voltage disturbances during a given time period. It can be expected that the marginal costs of a quality supply event declines with increased frequency, since the customers get used to them and adapt if the time interval between the events is large enough. But, the costs should be quite stable in a small time horizon, if the events do not occur with very small time intervals.

2.2.2 Interruptions characteristics

Interruptions can in addition be described with several other attributes as the duration of the interruption, if the customer was given an advance warning and the size of the affected area.

Duration
The duration of an interruption is, besides the time, an attribute of major importance. For many industrial and commercial customers however, it is the down-time of operations due to the interruption that is the key cost driver, and not the duration of the interruption itself. There are many examples of situations where even short interruptions may cause the need for rebooting of equipment in a time consuming process. Depending on the focus of the interruption cost estimation studies, different interruption durations are chosen in the scenarios. A usual duration range used in studies is from a few minutes to maximum 24 hours, but some studies covered also durations from less than one second to weeks. The studies normally specify four or five different durations in the different scenarios.

Advance warning
Advance warning is an attribute which is considered in many studies of interruption cost. The warning includes usually the information when and how long an interruption will occur. That means that a customer in case of a not notified interruption has also to deal with the uncertainty of how long it will last which can induce extra costs. The expectation is that a customer can undertake measures which will reduce the costs of the interruption if the customer was warned. It is recommended to pair a scenario with advance warning always with a scenario without warning and to present both to the same respondents.

Affected area
The size of the affected area where the interruption occurs is an attribute which can be included in the scenarios even though it is not that common. The affected area can have consequences on the total socio-economic costs since the spill-over costs are directly dependent on the area. In addition a widespread interruption complicates it to use alternative facilities since they also are affected of the interruption.

Cause of interruptions
The cause of an interruption should in theory have no effect on the costs since the consequences are equal, but some studies have looked into this attribute. In the real world it can happen that customers value electricity interruptions differently based on the cause since it can affect the

inconvenience of the customer in different ways. Customers could for example perceive events differently if it is caused by a terrorist act or a storm.

2.2.3 Voltage disturbances characteristics

It should be taken great care in describing voltage disturbance scenarios, since it is very difficult for most customers to separate between different voltage disturbance events. One example is separating between a voltage dip and a short duration interruption (e.g. 0.5 s). If the voltage dip is large enough (voltage drop and duration), many customers will perceive both these events as lighting and electrical equipment turning off for a fraction of a second without knowing if it was a dip or a short interruption. Another example is the difficulties of separating between a serious voltage swell and a transient overvoltage where the customers may typically perceive both as damage to some of the electrical equipment and appliances.

Harmonic voltages are furthermore a “stealth” voltage disturbance where the customers often will not notice any abnormalities such as changes in lighting intensity (as from interruptions, voltage dips, voltage swells etc) and in fact often not notice anything before damage or malfunction to electrical equipment or serious overheating occur. When such problems have occurred it is usually quite difficult to verify that the cause was harmonic voltages unless a measurement instrument is used to measure the conditions. The cause may however be found by experienced personnel when investigating for example traces of overheating in electrical equipment and appliances.

The costs of various voltage disturbances will, similarly to costs of interruptions, typically (but not necessarily) vary with the time of the occurrence and number of events etc. However, interruptions and voltage disturbances are very different phenomena, and the latter might be more an issue for professional customers than for Households.

2.2.4 Formulation and number of scenarios

Scenarios can be formulated in two different ways. The first approach is to confront the respondent with different interruption and voltage disturbance scenarios, where each is described by several parameters (for example an interruption in the winter). The second approach is to present the respondent with a quality of supply situation over a given time period with several quality of supply problems (for example two interruptions in the winter and a voltage disturbance each month during a year). The first approach has the advantage that it is easier to find the correlation between the attributes and the costs, whereas the latter approach allows for easy inclusion of frequency as an attribute.

It is also important to pay attention to which reference the scenarios are presented to since this differs for the two approaches. Usual methods are to compare with a situation with perfect quality of supply (i.e. no interruptions or voltage disturbances), to take the actual situation of quality of supply as a baseline, or to compare to a hypothetical base case. The first approach assumes usually that the respondent states the willingness to pay in comparison to a perfect power supply quality. That means the respondent quotes the willingness to pay that interruption does not occur at all. It is also common to define a base case and to compare other scenarios with it. The respondent has then to quote how the costs change relative to that case. This method is applicable for both approaches. The comparison to the actual quality of supply situation is most natural for the second approach, where the respondent get presented a scenario with a quality of supply situation over a given time period. The drawback of using a base case or the actual situation as a base line is that this may result in anchoring effects, i.e. the cost estimates are affected by the current situation and not fully to the underlying preferences and costs of the respondent.

Another fact which has to be considered is that there is a difference between asking about costs that will follow after a certain event on the one hand, and costs of being exposed to the risk of those events (ex ante) on the other hand. If it is a goal to capture the option value, the scenarios should be of the second type.

The possible number of scenarios is enormous since the number of possible combinations of the different attributes is so large. Questionnaires which include too many scenarios will probably result in low response rates and less effort by the respondents, which give problems for the analysis. Former surveys used usually between 4 and 10 scenarios, nevertheless surveys also contained considerably more scenarios.

It is therefore necessary to elaborate carefully which attributes and how many different values of each attribute to use in the survey. A given number of answers are required for each to ensure that the cost estimates are representative. The scenarios can be divided into sub-samples of the total number, if the total number of scenarios is too large to present in one questionnaire. Then the respondents are only confronted with an answerable sample of scenarios. This approach needs of course a higher number of respondents to cover all scenarios.

2.3 DESIGN OF QUESTIONS

This chapter will describe general aspects which have to be considered when designing a questionnaire. Concrete examples for questions and surveys can be found in the guideline in part A and in the appendix.

2.3.1 Contingent valuation studies and general advices

Contingent Valuation techniques have been under a lot of criticism for producing unreliable cost estimates. Some of the arguments are related to the method as such, hereunder the cognitive stress of expressing ones preferences in monetary terms, and probably the risk of extreme and strategic answers, and can only be met by choosing another method. However, other criticisms can be mitigated by an appropriate survey design and conduction. Even very simple questions require proper wording, format, content, placement and organization if they are to elicit accurate information.

In this section we will go through the most important recommendations for questionnaire design which can be found in the literature. A primary source is the report of the NOAA[18] Panel on Contingent Valuation (Arrow et al. 1993) as well as more recent OECD recommendations (Pearce et al. 2006) and the literature survey from the electricity sector (Bowitz et al. 2010). An important conclusion of the NOAA panel was that, following their recommendations, Contingent Valuation studies can produce estimates reliable enough to be used in a judicial process of natural resource damage assessment.

General advices

An accurate description of the scenario must be given, including three essential elements: A description of the measure to reduce quality problems, a description of the constructed market (who is responsible for providing it), and the timing of provision (when and for how long will the good be provided) as well as a description of the method of payment. The method of payment is non-neutral and should be considered thoroughly, as it is relatively common to find respondents refusing to answer the valuation question on the grounds that they object to paying higher prices or that they find the payment mechanism “unfair”. Respondents can only provide meaningful valuations if they accept the scenario and believe it to be feasible.

Careful pre-testing of the questionnaire is crucial: Respondents are often presented with a good deal of new and sometimes technical information, and it is necessary to make sure that respondents understand and accept the main description and questioning reasonably well.

It may also be appropriate to remind respondents about substitute commodities, as well as their budget constraints, before stating their preferences in monetary form. Respondents must be reminded that their willingness to pay for the program in question would reduce their expenditures for private goods or other public goods.

In general, the survey should include a variety of other questions that may help to interpret the responses to the primary valuation question. For example: prior knowledge and understanding of the task, and attitude towards utilities.

Note that some respondents in a survey may belong to more than one customer group. Especially, in a household one may find owners of firms – and perhaps also “third parties” (i.e. users of infrastructure in the region). The household’s cost estimate to avoid quality problems may be influenced by the respondent’s other roles. It is important to be aware of this when constructing the surveys, to avoid double-counting.

[18] NOAA (National Oceanic and Atmospheric Administration) has had an important role in developing central guidelines for Contingent Valuation studies. After Exxon Valdez spilt large amount of oil outside the coast of Alaska in 1989 Contingent Valuation was used to assess the society cost. In response to critiques of contingent variation methods, NOAA established a panel of acknowledged economists (like Nobel Price laureates Kenneth Arrow and Robert Solow) to assess the method and give recommendations about design. These guidelines are still today considered State-of-the-Art.

Question-answer format

The format of the questions and answers should be in a format that people are used to. It can be chosen between open-ended and closed-ended formats. Open-ended formats give no answer alternatives, whereas close-ended format are limiting the answer alternatives. The following simple example shows the differences between the two formats.

What was the total electricity consumption in the last year [kWh]?	
Open-ended format	Closed-ended format
_____________ kWh	□ 0 – 1000 kWh □ 1000 – 10000 kWh □ 10000 – 50000 kWh □ > 50000 kWh

In principle, the open-ended question is the most optimal because it does not provide the respondent with anchoring or starting point biases. It gives all the necessary information in one question and is therefore also an efficient way to collect data. However, when respondents find it difficult to express their willingness to pay in monetary terms, or have strategic behaviour, open-ended questioning may lead to large non-response rates, extreme answers and outliers. In addition, this format does not present a normal purchase decision, as most daily transactions involve deciding whether or not to buy goods at given prices, rather than expressing ones maximum values. Therefore, closed-ended formats are often recommended in the literature. But one challenge with the closed-ended format is that an adequate range of answer values has to be constructed. If the values presented are not adequate to the respondents the results will be influenced.

There is a variety of closed-ended alternatives to the simple open-ended format: For example the iterative bidding-game (auction) format, the use of payment cards (respondents are presented with a visual aid containing a large number of monetary amounts which facilitates the valuation task) or using dichotomous choice or referendum methods (respondents only have to make a judgement about a given price, in the same way as they decide whether or not to buy a supermarket good at a certain price; “Would you be willing to pay X for...”, Yes/No). The NOAA panel recommended the referendum format. However, no final conclusion is made in the literature about one question format being superior to the others.

2.3.2 Conjoint Analysis studies

The general considerations done in the foregoing chapter are also valid for surveys based on Conjoint Analysis. In addition, the fact that the respondent is confronted with two or more scenarios at the same time has to be considered. The setup for the answers can be designed in three different ways: ranking, rating or choice experiment.

Ranking and rating

The ranking approach asks the respondent to rank the scenarios from least preferable to most preferable. This can be done by ranging the scenarios (ordinal ranking) or by using a cardinal rating scale to obtain more information about the gap between the attractiveness of different scenarios (cardinal rating). Cardinal rating is more demanding to the respondent and it has to be decided how many different steps the scale should include (two former studies which used Conjoint Analysis used a scale from 1 to 10 to rate the scenarios). The criticism against rating marks is that it assumes the comparability of the ratings of different customers and therefore that all customers have the same understanding of the different rating marks.

Choice experiment[19]

Another common approach of designing a Conjoint Analysis is the use of choice experiments. In a choice experiment the respondent has to choose the preferred scenario out of two or more alternatives. The decision of which scenario to choose is arguably easier for a respondent than to rank or rate different alternatives, and much easier than reporting a monetary value in a Contingent valuation study.

All scenarios will need a price tag as an attribute. Moreover, the willingness to pay can only be estimated if at least one of the scenarios contains a change in electricity costs. Recent research found that neither the design of the first choice set nor the number of choice sets has a significant impact on cost estimates, but they found an effect for the choice of attribute levels.

2.4 CONDUCTION METHODS AND RESPONSE RATES

After the questionnaires are designed, it has to be determined when and how to approach the customer. When a survey is implemented after a real interruption case, the survey must be conducted at a time sufficiently distant from the event, that respondents regard the scenario of complete restoration as plausible. Besides this, the timing of the survey has no effect on the cost estimates according to a recent study of Baarsma and Hop (2009). Thus, it is not important if a survey is conducted for example in the winter or in the summer.

There are several methods to conduct the actual survey; particularly there are different ways to approach the respondents. The most relevant options are:

- Face-to-face interview
- Postal survey
- Telephone interview
- Web based survey.

When making the decision, it is important to consider how to obtain an acceptable response rate at lowest possible cost, and at the same time to ensure that the questionnaire is answered by the correct people within the company or household, and that respondents are guided well through the questionnaire and followed up on extreme answers and missing answers. The following table presents the advantages and disadvantages of the most relevant conduction methods. The presented response rates are more general and can differ significantly depending on the country.

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[19] More comments on how to make and select choice sets for a choice experiment can be found in Concept Economics (2008).

Table 12: Overview of conduction methods (Source: Pearce and Özdemiroglu 2002)

Method	Advantages	Disadvantages
Face-to-face interviews Interviews take place one-to-one between the interviewer and the respondent either at home or another location relevant to the study (intercept survey)	Highly flexible Complex questions and questionnaire structures are possible Permits probing and clarification Larger quantity of data can be collected Potential for extensive use of visual and demonstration aids **High response rates 70%+** Greatest sample control	**Relatively expensive** Possible interviewer bias High demand on the interviewers competence Intercept surveys: samples normally not representative and self-selection bias Intercept surveys: questionnaires have to be short
Postal surveys Printed questionnaires are posted to potential respondents	**Relatively inexpensive** Lack of interviewer bias Easier to answer sensitive questions Can be completed at respondent's own pace	**Low response rates 25-50**% Self-selection bias Time-consuming No clarification or probing possible Little control over who fills the questionnaire Fixed question order Restricts the use of visual aids Respondent can alter earlier responses
Telephone interviews Interviewers call potential respondents	Complex questionnaire structures are possible **Cheaper than face to face interviews** Permits probing and clarification Relatively quick to administer Easy to monitor **60-75% response rates**	No use of visual aids Restricts use of lengthy scales Respondent may get tired Respondents may not answer sensitive questions Non-telephone or non-listed respondents not sampled
Web based surveys Respondent answers to questions on computer	Subsequent analysis is quicker since data inputting stage is not necessary Permits more complex interviews Permits use of e-mail and internet	Possible rejection of 'computer technology' E-mail/internet may preclude random sample unless wide coverage of PCs and internet connections
Mixed methods: drop off survey The questionnaire is mailed prior to a visit by the interviewer	Initial personal contact gives survey a 'human face' Shares the advantages of mail and face-to-face methods	Survey form may be lost in interval before calling back Expensive
Mixed methods: mail + telephone surveys The questionnaire is mailed prior to a phone call by the interviewer	Gives personal touch to the survey Can complete mailed questionnaire in own time	Shares some of the limitations of mail surveys Relatively expensive
Mixed methods: telephone + web based surveys The questionnaire is called prior to sending the questionnaire by email	Gives personal touch to the survey Correct respondent can be identified Can complete mailed questionnaire in own time	Shares some of the limitations of web based surveys Relatively expensive

The NOAA panel recommended that face-to-face interviews should be used in stated preference studies, because they believed that it is unlikely that reliable estimates of values could be elicited with mail surveys. Even though their concern was environmental goods, which are probably even more difficult to value than quality of electricity supply, it is a fact that personal interviews give the best opportunity to assist the respondent through the questionnaire and make sure the scenarios are understood and that the value estimates are realistic. The same argument could probably be used about Direct Worth studies. It is also important to make sure that the correct person answers the questionnaire (especially when approaching business customers). This can only be assured by going through the questionnaire with him or her. But face-to-face surveys are very costly. Even though, this approach was chosen in an Italian survey (Bertazzi et al. 2005) due to low response rates on other conduction methods. 1100 households, as well as 1500 industrial and commercial customers were interviewed face-to-face during that survey.

In some cases, however, if there is a social pressure to express a certain type of answer, anonymous surveys could be an advantage. This is not assumed to be a problem if the questions are all about the customer's costs only, but possibly if the questionnaire also includes questions about the value of reliability in critical infrastructure.

From a cost perspective, postal and web based surveys are to be preferred. However, it is typical that the response rate is negatively correlated with the costs of the different conduction methods and is normally highest for face-to-face interviews. The expected response rate in postal and web based surveys must be assessed on a country-to-country basis, as this may depend on how accustomed people are to participating in such surveys. A common 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 it can be obtained an acceptable response rate in a cost efficient way. Response rates, especially from Households, can also be increased by implementing some kind of incentives for answering the questionnaires (lottery tickets or other). The following figure gives an overview of response rates and sample sizes of cost estimation studies in different countries in the recent years.

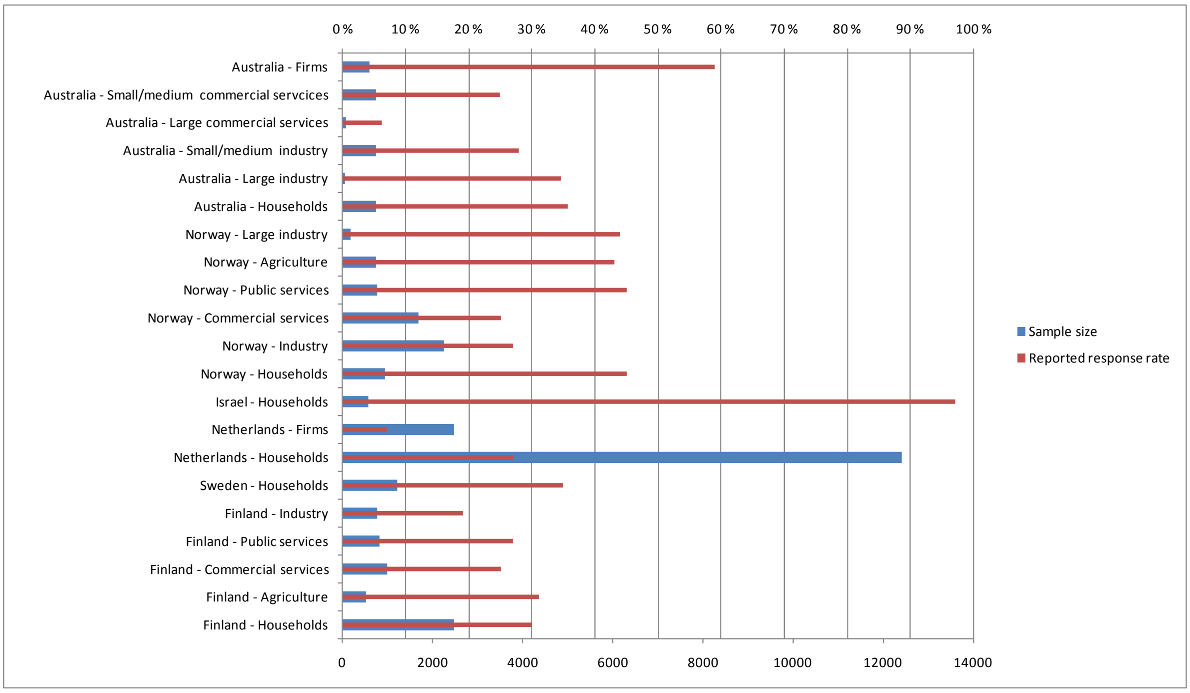

Figure 15: Response rates of different countries and customer groups

Figure 15 presents only the reported response rates which usually means returned questionnaires. It has to be considered that the final responses which can be used for the cost analysis can be significantly lower due to not complete answered questionnaires. This fact will be illustrated with the response rates of a Norwegian survey as presentend in Table 13. The reported response rates in terms of returned questionnaires were for example 27 % for the Industry. But the final sample used for cost estimation is significantly lower due to not complete answered questionnaires and censoring. For example, only 50 % of the main cost estimation scenarios were answered in the returned questionnaires of the Industry which led to an average response rate over all cost estimation scenarios of 12 %. This effect has to be considered when the sample size has to be defined.

Table 13: Response rates of Norwegian survey (Source: Kjølle et al. 2008)

					Sample used for cost estimation	
	Sample size	Real sample after repeal	Responses	Response rate	Absolute (average of all scenarios)	Relative to real sample
Households	1000	944	425	45 %	325	34 %
Industry	2400	2259	618	27 %	280	12 %
Commercial services	1800	1678	425	25 %	160	10 %
Public services	800	769	347	45 %	85	11 %
Agriculture	800	747	321	43 %	155	21 %
Large industry	220	176	78	44 %	35	20 %

2.5 SAMPLE SIZE AND SAMPLING OF THE POPULATION

After the survey has been designed the size of the sample of respondents should be selected to obtain a representative sample. It is necessary that the sample provides a good representation of the customer groups and in sub-samples of interest and is closely connected to the response rate of the customers. This is particularly important since cost estimates can vary considerably between different individual customers. The following objectives are important for the sample design:

- Minimising the bias in the cost estimate so that the cost estimate is on average correct, for the customer group in question
- Minimising the uncertainty in the cost estimate both overall and for different customer groups
- Allowing for separate analyses for different customer groups.

The original population is often defined through industrial classifications and databases, power company customer lists, address registers or other databases as the white or yellow pages. It can also be discussed whether a sample should be based exclusively on customers which experienced interruptions or voltage disturbances. This approach has the possible advantage that these customers can give a more reliable cost estimate, but it also has several drawbacks. The experienced quality of supply problems are very specific situations and therefore not representative for a general cost assessment, where the goal is to find cost estimates for quality events with varying characteristics. Furthermore, such an approach could only cover cost estimates from customers in affected areas, and not the whole population, which makes it difficult to have a representative sample. Besides, the customers could be subjected to recall errors if they had experienced several interruptions. Because of the presented drawbacks, it is not recommended to conduct a survey exclusively on experienced customers. The quality of power supply is generally high in European countries and such an approach would limit the population for the survey and it can also be expected to get mainly cost estimates for shorter interruptions, which occur usually more frequent. Another drawback is that asking about costs based on a certain event does not capture the option value as asking for hypothetical scenarios do.

The sample size is directly dependent on the expected response rate which again is dependent on several factors. Besides country specific reasons, the length of the questionnaire, the number of scenarios and the type of survey conduction have a large influence on the response rate. The following formula can be used to get an approximate for the sample size depending on the expected response rate, the expected spread in the cost estimation and the requested significance of the results.

$$n = \left(\frac{S \cdot 2 \cdot Z_{\frac{\alpha}{2}}}{L}\right)^2$$

n – Number of respondents needed
S – Standard deviation
$Z_{\alpha/2}$ – Z-value depending on the distribution and the confidence level
L – Length of the confidence interval

$$N = \frac{n}{R}$$

N – Sample size
R – Response rate

In the following a general example is given for sample sizes based on the equation.

Confidence interval	± 25 % mean
Confidence level	95 %
Zα/2	1.96 (assumes normal distribution)

General examples

Standard deviation (% of mean)	Response rate	Sample size
100 %	20 %	307
200 %	20 %	1229
300 %	20 %	2766
400 %	20 %	4917

Groups can be combined to reduce the sample size of the whole survey. Combining groups has several advantages and disadvantages.

- Advantages
  - Cost saving in the design of questionnaires
  - Cost saving through lower sample size (if cost estimates are similar of the groups)
  - Cost estimates can be estimated representative for customers in the same sector
- Disadvantages
  - Larger spread of the cost estimates
  - Lower response rate due to bad fitting/less relevant questionnaires to some customers
  - Average cost estimates more unreliable due to larger dispersion.

The standard deviation of the combined cases can be calculated according to the following formula.

$$S_{combined} = \sqrt{\frac{\sum_i n_i(S_i^2 + M_i^2)}{\sum_i n_i} - M_{combined}^2}$$

S – Standard deviation
n – Number of respondents
M – Mean

In the following an example is given illustrating the effect of combining groups. The sample size may be reduced when the two groups in the example are combined. But lower response rates counteract that effect and can lead even to higher sample sizes needed.

Confidence interval	± 25 % mean
Confidence level	95 %
Zα/2	1.96 (assumes normal distribution)

Example for combining two customer groups

(based on censored data from Kjølle et al. 2008)

	Mean (NOK/kWh)	Standard deviation (NOK/kWh)	Response rate	Sample size
Industry	123	140	27 %	295
Commercial	201	246	25 %	368
				663
Combined (average response rate)	165	265	26 %	**611**
Combined (lower response rate)	165	265	20 %	**795**

The combined standard deviation of the example is calculated as follows.

$$S_{combined} = \sqrt{\frac{80 \cdot (140^2 + 123^2) + 92 \cdot (246^2 + 201^2)}{80 + 92} - \left(\frac{123 + 201}{80 + 92}\right)^2} = 265$$

Based on this, the number of respondents needed is calculated as follows.

$$n = \left(\frac{265 \cdot 2 \cdot 1.96}{2 \cdot 0.25 \cdot 165}\right)^2 = 159$$

The sample size can be calculated by taking into account the response rate.
Combined (average response rate):

$$N = \frac{159}{0.26} = 611$$

Combined (lower response rate):

$$N = \frac{159}{0.2} = 795$$

If the sample size is decided, a representative sample has to be selected. This is usually performed with some kind of random sampling method. The most used technique is to take a random sample from the original population in each customer group. It is often difficult to get representative cost estimates for larger customers with this technique since small customers are overrepresented in the population and only few cost estimates for Large customers can be obtained. A method to handle this issue is to use the sampling method “probability proportional to size”. In this sampling method the probability of selecting each firm into the sample, is proportional to its size. Size attributes can be the yearly electricity consumption, number of employees or turnover.

Another procedure to ensure representative data is stratified sampling. The stratification can be done by the company sector, the region, the size or other characteristics of the customers. For example, the industrial customers can be divided into sub-populations according to the industrial classification scheme and with stratified sampling it can be ensured to get representative results for each of these groups. The number of sub-population besides the defined customer groups has to be seen in relation to the volume and cost of the survey. A more detailed grouping will need more respondents.

The short description and the main advantages of different sampling methods are presented in the following table.

Table 14: Overview sampling methods (Source: Pearce and Özdemiroglu 2002)

Form of sampling	Method	Advantages
Simple random	Every element of the sample frame is given an equal chance of being selected.	Simple
Systematic	Select every k^{th} element from a randomly ordered population frame.	Simple
Stratified	Sample frame population is divided into distinct sub-populations, or strata. A separate and independent sample is selected for each stratum, using random sampling with either the same sampling fraction for each of the strata (proportionate stratification) or different sampling fractions (disproportionate stratification). The data are used to develop separate within-stratum estimates. Finally, the separate stratum estimates are combined (weighted) to form an overall estimate for the entire population.	Enables estimates to be derived for each sub- group, even though sub-group may be a small fraction of the population.
Clustered multi-stage	Population is divided into a set of groups or 'clusters' but only a random sample of the clusters is selected. Cluster sampling involves sampling all the elements within the selected clusters, but the term is also used to cover multi-stage sampling, in which one selects only a random sample of the elements within the selected clusters. An example of cluster sampling would be to divide a city into zones, randomly select a set of zones, and then survey every household within the selected zones. In a multi-stage sample, one would survey only a sample of households within the selected zones.	For surveys of large populations that possess some sort of hierarchical structure, multi-stage sampling is generally more convenient and more economical than one-stage simple random sampling. Multi-stage sampling is attractive when no overall sample frame is available.

However, even a careful sampling cannot ensure that the returned questionnaires will still give a representative sample since the response rates from different sub-groups can be different. For example an overrepresentation of old people could be observed after the conduction of the survey, since this sub-group of customers had a higher response rate than the rest of the population. Therefore the returned sample of questionnaires has to be checked again for representativeness (see next chapter).

2.6 TESTING THE DESIGN OF THE SURVEY

It is recommended to test all aspects of the survey. That means to test if the scenarios are understood, questions are formulated in a clear way, and if the range of answer values are representative. In addition, different length of questionnaires as well as different ways of approaching the customer can be tested from cost and response rate perspective. A common approach to test the complete survey design is through focus groups and/or pilot surveys. A focus group consists of some customers of the customer group of interest. They are asked in direct contact about their opinions about the questionnaire presented. The questionnaire is good designed, if they accept the scenarios as relevant and understandable. Pilot surveys are conducted on the same premises as the final survey but on a smaller sample. Through this approach the survey can be tested under real life conditions and last small changes can be implemented to improve the design of the questionnaire or the method of conduction. In addition, an indication of expected response rates can be obtained through the pilot study, which is a useful input to decide on the final sample size.

Another approach to improve the quality of the survey and the overall results is to combine surveys with experimental methods or laboratory experiments. The experiments can be used to improve the survey design, as well as being useful to calibrate survey results in an ex-post perspective.

3 COST ESTIMATION FROM SURVEY DATA

The data obtained from the respondents in a customer survey is the raw surveyed data. This represents the actual cost that a particular customer will experience if a given interruption scenario or voltage disturbance occurs. These data are simply given in monetary units[20] per incident.

The raw cost data obtained through the questionnaire is the basis for estimating cost data for various purposes such as

- Calculate overall (weighted average) cost estimates;
- Calculate cost estimates for each of the individual customer groups considered in the survey;
- Describe the relationship between the cost estimates and the different dimensions of a quality of supply problem.

For these purposes the raw data need to be transformed into usable cost parameters. The following sections describe how the data have to be prepared upfront to the analysis and how the cost estimates or cost functions can be established according to the different objectives.

3.1 PREPARATION AND NORMALIZATION OF COST DATA

The preparation of data involves three steps; quality assurance of raw data, normalization of data and handling of outlier values and zeroes.

The description given in the following sections assumes that the individual respondents' cost data are revealed through the survey. In Contingent valuation (Direct Worth, WTP and WTA) these data are explicitly surveyed, while if the Conjoint analysis method is used in the survey the willingness to pay or accept should first be estimated based on the Conjoint analysis and using an econometric model, i.e. to transform the information into raw cost data. There exists a rich econometric literature on how to estimate these cost parameters from various types of Conjoint Analysis. The econometric methods depend very much on the survey design (use of ranking, rating or choice experiment).

In the Conjoint Analysis known as choice experiments, the respondents chooses their preferred scenario out of pairs of scenarios, and this data structure naturally has implications on how to estimate the respondents willingness to pay. The common approach to estimate costs from choice experiments where the respondent chooses the preferred scenario out of pairs of scenarios is "Random utility models". This results in discrete choice models of the logit and probit type. These models essentially explain the probability that a given customer will prefer a specific choice depending on interruption attributes and customer characteristics. This type of model can be estimated through standard multinomic logic methods.[21]. Among more sophisticated models are

[20] In this report we use Euro (€) as the general currency.
[21] Concept Economics (2008) give a more thorough description on the whole subject.

the Random Parameter Models. A Random Parameter Model allows the parameters of the utility function to have a distribution, whereas the parameters are usually fixed. We have not made a summary of methods used on the other conjoint methods, that is, ranking or rating.

Quality assurance of raw data

The raw data should be examined for wrong and missing data and if the real responses are representative of the random samples. In the first step the data have to be corrected for obvious wrong data due to careless response, misinterpretation, punching errors and other. Wrong data might also occur if respondents were allocated into wrong customer groups. Examples of wrong data are given below:

- The respondent has stated costs that exceed his turnover
- Willingness to pay values higher than willingness to accept or Direct worth values
- There is no correspondence between the electricity consumption in kWh and in monetary terms (total annual cost of electricity).

In theory the willingness to pay estimate should be higher than the Direct worth estimate, since it also includes non-monetary costs in contrast to the Direct worth estimate. But in practice, the willingness to pay estimate is always lower due to the high loss aversion of the respondents. It means that the effect of loss aversion outweighs the non-monetary costs significant.

As shown by the examples presented in this report the response rates from such questionnaires are typically low (20 % – 40 %), meaning that the major part of the questionnaires are not returned. In addition some of the questions of those received might not be replied at all or not answered properly.

It is possible to correct wrong and missing data manually questionnaire by questionnaire (for a person with the right competence) and as such increase the number of correct responses. However in practice, this will be a too demanding task for surveys containing thousands of returned questionnaires. Obvious wrong values can be identified by executing logical tests (automatic) in the data material for the examples above, e.g. check if cost estimates are exceeding annual turnover and check if the annual electricity consumption given in monetary terms corresponds to the kWh value. This can be checked using information about tariffs from public sources.

Missing data can to some extent be imputed combining information stated by the respondent with information from other public sources. For instance the electricity consumption in kWh may be estimated based on the respondent’s stated cost and the tariff.

Examples from customer surveys on quality of supply problems show that a large share of the respondents report zero costs for some interruption scenarios or voltage disturbances (both measured as willingness to pay in Contingent valuation designs and in direct cost assessments). These values should be treated as zeroes and not as missing data. Thus, it is important not to substitute missing data by zero values in the data quality assurance procedure, being particularly careful for questions asking for certain values. Protest answers can be excluded. An approach for identifying protest answers based on zero values are described in the section of handling of outliers and zeros later on.

If logical tests reveal wrong values that can not be substituted by correct values or missing data may not be imputed, the response for the specific question or part of the questionnaire should be excluded from the final sample that will be used to develop cost parameters. However, this might affect only parts of a response and the non-missing data should be kept for further analysis.

It might be questionable whether or not the real collection of responses is representative for the random samples. Lack of responses might give misleading estimates in case of systematic repeal. This can be tested using statistical test. In the Norwegian survey (Kjølle et al. 2008) for instance statistical t-tests were performed along the geographical dimension as well as within each group according to size. It was a tendency that small sized enterprises in the commercial sector were more willing to respond than larger companies, while it was the opposite for the industrial sector. However, the tests showed that the lack of responses did not lead to any significant imbalance according to the size of the enterprises or e.g. the age of residential customers, neither according to the geographical dimension. The test results showed that there was no reason to believe that the missing questionnaires would give significant and systematic deviations.

Normalization

The cost estimates from the respondents are usually stated in absolute cost for a given interruption or voltage disturbance scenario. The raw (surveyed) data need to be transformed into normalized data that can be used to represent customers within the same sector (i.e. with similar cost characteristics and different electricity consumption level) and to provide cost data on a usable form for different applications. For most of the applications regarding regulatory purposes as well as planning and operation of the power system it is appropriate to use a measure of installed/demanded power or energy for the normalization (Billinton et al. 2001). Applied normalization factors include power (kW) not supplied also termed interrupted power, energy (kWh) not supplied, annual electricity consumption (kWh) and annual peak load (kW).

The normalized (specific) cost for a certain respondent and for a given scenario at reference time *t* can be represented as follows:

$$c_{N,i}(r,t) = \frac{C_i(r,t)}{N_i(r,t)} \quad [\text{€/kWh or kW}] \qquad (1)$$

Where

$c_{N,i}(r,t)$ = Normalized (specific) cost for respondent *i* for an interruption of duration *r* or voltage disturbance occurring at time *t* [€/kWh or kW]

$C_i(r,t)$ = Monetary value of respondent *i* (from the survey) for an interruption of duration *r* or voltage disturbance occurring at time *t* [€]

$N_i(r,t)$ = Normalization factor for respondent *i* in [kWh] or [kW]

The normalized cost in (1) can now be used to calculate the cost per interruption, i.e. the cost of a specific interruption, for a given customer in the corresponding customer group can now be calculated as follows:

$$C_k(r,t) = c_{N,s}(r,t) \cdot N_k(r,t) \text{ [€/kWh or kW]} \qquad (2)$$

Where

$C_k(r,t)$	=	Monetary value for a customer *k* of sector *s* for an interruption of duration *r* or voltage disturbance occurring at time *t* [€]
$c_{N,s}(r,t)$	=	Normalized (specific) cost for sector *s* for an interruption of duration *r* or voltage disturbance occurring at time *t* [€/kWh or kW]
$N_k(r,t)$	=	Normalization factor for customer *k* in [kWh] or [kW]

The cost for a given interruption is found as the product of the normalized cost data from the corresponding customer sector and the customer's normalization factor, i.e. corresponding to the type of normalization factor used to calculate the normalized cost data.

The reference time used in the survey (see reference scenarios in part A of the report) represents the time *t* in the expression of the normalized cost. As shown by the examples of data collected through customer surveys, for instance the cost of interruption varies considerably by time of day and day of week and sometimes by season in addition to the duration of interruption. This should be taken into account in the application of the cost estimates. An approach for handling the time dependency in interruption costs is described in next section.

Using energy not supplied or interrupted power as normalization factors requires information about the electricity demand curves of the different customers. These data are not always easily available unless automatic reading of hourly measurement is implemented for each customer. Some countries have developed some general load curves that can be used to estimate interrupted power and energy not supplied. Energy not supplied and interrupted power varies with time, however not directly proportionate to the cost. Using these variables as normalization factors requires a representation of the time variation in both the costs and the normalization factors. Estimation of energy not supplied and interrupted power is e.g. thoroughly described in (Kjølle et al. 2008) while how the time variation can be handled is described in (Kjølle et al. 2009).

In the following a description is given on the standardized method in Norway for estimation of energy not supplied using load curves. The description is taken from (Kjølle et al. 2008).

> Energy not supplied (ENS) is defined as *the estimated energy that would have been supplied if the interruption did not occur*. Estimating ENS would ideally be carried out by finding the integral under the load curve for equivalent conditions (customer type, temperature and season). Due to lack of such detailed information ENS is estimated by means of hourly average load, as illustrated in Figure 1.

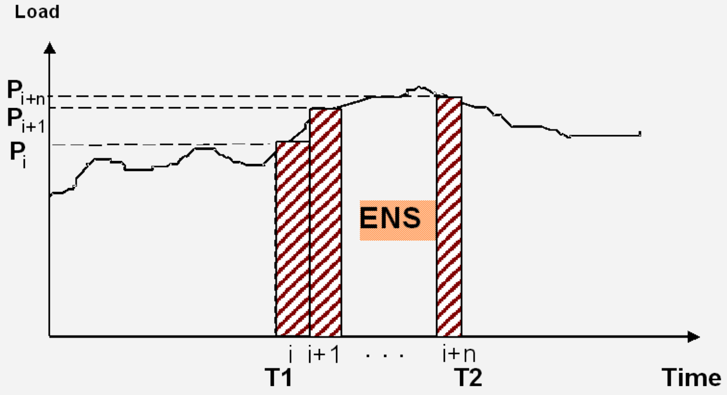

Figure 1 Approximation of ENS based on hourly average load.

Estimation of ENS for an interruption with duration from T1 till T2 (Fig. 1) is carried out by the following approximation:

$$ENS = \int_{T1}^{T2} P(t) \approx \sum_{h=i}^{h=i+n} P_h \quad \text{[kWh]} \qquad (1)$$

Where P_h = average load in any hour *h* [kWh/h]

The electricity consumption in Norway (heating in particular) is highly dependent on outdoor temperature. Consequently, temperature dependent load profiles have been established for all the surveyed end-user groups and for all climatic zones. For the purpose of estimating normalized 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.

The average load ($P_{c,z,h}$) in any hour *h* for end-user of category *c* in climate zone *z* is estimated according to (2):

$$P_{c,z,h} = a_{c,z,h} \cdot t + b_{c,z,h} \quad \text{[kWh]} \qquad (2)$$

Where

$a_{c,z,h}$	=	Coefficient for hour *h* for end-user of category *c* in climate zone *z* [kWh/°C]
t	=	Daily mean outdoor temperature [°C]
$b_{c,z,h}$	=	Average load at 0 °C for end-user of category *c* in climate zone *z* [kWh/h] for hour *h*.

Since the questionnaire asked for electricity consumption for year 2000 the normal yearly electricity consumption for each respondent for this year (Wc,z,2000) was estimated based on (2) and the temperature-series for year 2000.

The percentage ($p_{c,z,h}$) of the yearly consumption per hour in year 2000 is considered to be the same as in a normal year, and is found by (3):

$$p_{c,z,h} = \frac{(a_{c,z,h} \cdot t_{n,z,d} + b_{c,z,h})}{W_{c,z,2000}} \cdot 100\% \qquad (3)$$

Where

$t_{n,z,d}$ = Daily mean temperature on day *d* in climate zone *z* in a *normal year*

$p_{c,z,h}$ values were calculated for all climate zones and different end-user categories. Each set consists of a full year time-series (8760 values).

Energy not supplied (ENS) in hour *h* for a respondent *i* of end-user-category *c*, located in climate zone *z*, can then be estimated using the formula in (4):

$$ENS_{i,c,z,h} = p_{c,z,h} \cdot W_{i,2000} / 100\% \text{ [kWh]} \qquad (4)$$

Where

$W_{i,2000}$ = Yearly electricity consumption in year *2000* for respondent *i* (from questionnaire)

Furthermore ENS for an interruption of duration *r* occurring at time *t* is given in (5), using (1):

$$ENS_{i,c,z}(r,t) = \sum_{h=t}^{h=t+r} ENS_{i,c,z,h} \quad \text{[kWh]} \qquad (5)$$

This expression gives the normalization factor for long interruptions (> 3 min.) for a given respondent *i* of end-user category *c* and climate zone *z*.

The normalization factor for dips and short interruptions (≤ 3 min.) is the interrupted power in kW, defined as *the estimated power that would have been supplied at the time of interruption (or voltage dip) if the interruption (dip) did not occur* [16]. The interrupted power is similarly estimated using hourly loads according to the above procedure.

To avoid dealing with two time varying parameters, it might be more convenient to use a constant normalization factor, such as the annual electricity consumption, the annual peak load or the average load. The annual electricity consumption can usually be collected through the survey (or imputed as described above if information is given about the electricity bill and the tariffs). The average load can be derived simply dividing the annual consumption by 8760 hours, giving a kW per hour value. When it comes to the peak load however, this parameter is expected to be difficult for the customers to give information about. The annual peak can be defined as the highest hourly load during a year. These data might be available from the network company otherwise they would need to be estimated on the basis of load curves. Another parameter similar to annual peak load that may be used as normalization factor is the interrupted power, i.e. the hourly load at the *reference time* of the survey. This needs similarly to be estimated from load curves.

The choice of normalization factor will partly depend on available data and partly on how the cost estimates will be used. An example is the Norwegian cost of energy not supplied scheme starting in 2001 for long interruptions requiring costs estimates referred to energy not supplied. This was the reason for choosing energy not supplied as the normalization factor, using cost figures derived from the previous customer survey in 1991. However, this required a standardized method for estimation of energy not supplied which is described in FASIT, the Norwegian standard for collecting continuity of supply data. For the same reason and for comparison purposes energy not supplied was again chosen as normalization factor for the survey in 2002. For the inclusion of short interruptions the cost data was from 2009 represented as continuous cost functions in terms of costs per kW interrupted power. This is described in Chapter 4, part B.

Cost data can also be normalized with other factors with no connection to the electricity consumption, as for example the yearly turnover. Since the normalized cost data will be used together with data corresponding to the normalization factor, SINTEF recommends using a factor based on electricity demand/load shown in Table 15, preferably a constant such as annual electricity consumption, average load, peak load or interrupted power at reference time. Energy not supplied varies from interruption to interruption as a function of both the load at the time of occurrence and the duration. However, an advantage of using energy not supplied is that this is a common parameter in reliability analyses, for planning purposes and sometimes in financial incentive based regulation schemes. Interrupted power will similarly vary by time of occurrence, but if this parameter is estimated at reference time of the survey, it can be regarded as a constant.

Table 15 Different normalization factors based on electricity demand/load

Factor	Definition	Type of data required
Annual electricity consumption (kWh)	The total annual electricity consumed	Total annual electricity consumption monitored as input to the electricity bill
Average load (kWh/h = kW)	Annual electricity consumption/8760	Total annual electricity consumption monitored as input to the electricity bill
Peak load (kWh/h = kW)	The maximum hourly load in the year	Load data: 8760 hourly loads based on hourly metering or general load curves for estimation
Interrupted load (kWh/h = kW)	The estimated power that would have been supplied at the time of interruption (or voltage disturbance) if the interruption (disturbance) did not occur	Load data: 8760 hourly loads based on hourly metering or general load curves for estimation
Energy not supplied (kWh)	The estimated energy that would have been supplied if the interruption did not occur.	Load data: 8760 hourly loads based on hourly metering or general load curves for estimation

Handling of outliers and zeroes

Outliers and zero values can have a large influence on the estimated average costs for various customer groups. An example of how censoring influences the dispersion in the data is given in the Norwegian survey from 2002 (Kjølle et al. 2008). The standard deviations for the normalized and censored costs were about 1 – 2 times the mean values, while for the uncensored costs the standard deviations were in the order of 2 – 5 times the mean values for the six customer groups surveyed.

As stated above in the quality assurance step, the zero values should be treated as zero values even if this gives highly skewed distributions. Zero values for willingness to pay estimates can be protest answers, but also true values. It is always challenging to distinguish between these two cases. Protest answers can possibly be identified by the following approach. An indication for protest answers is given, if the same respondent, who declared a zero willingness to pay, has very high cost estimates for the Direct worth and the willingness to accept estimates compared to other respondents of the same customer group. The comparison has to be performed on normalized data. If this indication is given, one can assume that the respondent answered with protest to all cost estimation questions.

Regarding outliers it is often uncertain whether for instance extremely high cost values are correct representations of the costs or if they are errors due to punching mistakes, or if they even are results of protest or strategic answering. Outliers can be excluded from the data material. If so the key issue is to define an objective rule for identification of outliers. This is a common approach and usually done by truncation of all values above or below a boundary value. The boundary value can be defined in relation to the standard deviation, for example to eliminate all values higher than twice the standard deviation with reference to the normal distribution. However, survey results typically show that the data are not normally distributed. The distributions are often highly skewed. Examples show that the data can be represented by a lognormal distribution (Kjølle et al. 2008, Billinton et al. 1994, Ghajar et al. 1996). Before censoring of outliers the (normalized[22]) data can then be transformed to a normal distribution using a lognormal transformation. An example of a quality assurance and censoring procedure is given in Figure 16 below.

[22] The censoring procedure is usually carried out for the normalized data (meaning data normalized by e.g. annual electricity consumption).

- Data segmentation into sectors
    - Industry
    - Large industry
    - Commercial
    - Residential
    - Agriculture
    - Public sector
- Logical tests to handle
    - Careless response
    - Misinterpretation
- Lognormal transformation of sector normalized sample data
- Censoring of outliers based on pre-defined criteria
- Re-transformation [a'= exp(a)].
- Result: Censored normalized data in original format.

Figure 16: Algorithm for quality assurance and censoring of data[23] (Kjølle et al. 2008)

Even though, if the outliers are handled by censoring, the resulting data have to be tested if they are representative as described above.

Nevertheless, there is also criticism against this kind of censoring of outliers. It is argued that outliers indicate that the respondents in the selected customer groups are very heterogeneous. Therefore the customer group should be divided into more subgroups. An exclusion of outliers is likely to lead to inefficient cost estimates in these cases.

SINTEF recommends performing quality assurance of the data to sort out obvious mistakes, but not necessarily to censor the data. First of all valuable data are neglected if data are censored and it might also lead to wrong conclusions when cost results show less dispersion than they do in the reality. If it is decided to censor outliers, the approach has to be used carefully and the criteria for identification of outliers should be documented. Under any circumstance SINTEF recommends to present the whole distribution of the data together with different measures of dispersion such as standard deviation, maximum and minimum values, 95 percentile etc. An example is given below in Table 16 and Figure 17 below for the normalized cost of 4 hour interruption for Industry.

Table 16: Normalized cost for Industry in NOK/kWh energy not supplied, Norwegian survey 2002

Industry (NOK/kWh)	Mean	Standard deviation	Maximum	Minimum
4 hour interruption	107,3	137,5	767,8	2,5

[23] Samdal et al. 2006 gives a thorough description and discussion of the censoring procedure used in the Norwegian survey 2000 – 2002. Kivikko et al. 2007 describes the approach for censoring used in the Finnish survey 2004 – 2005.

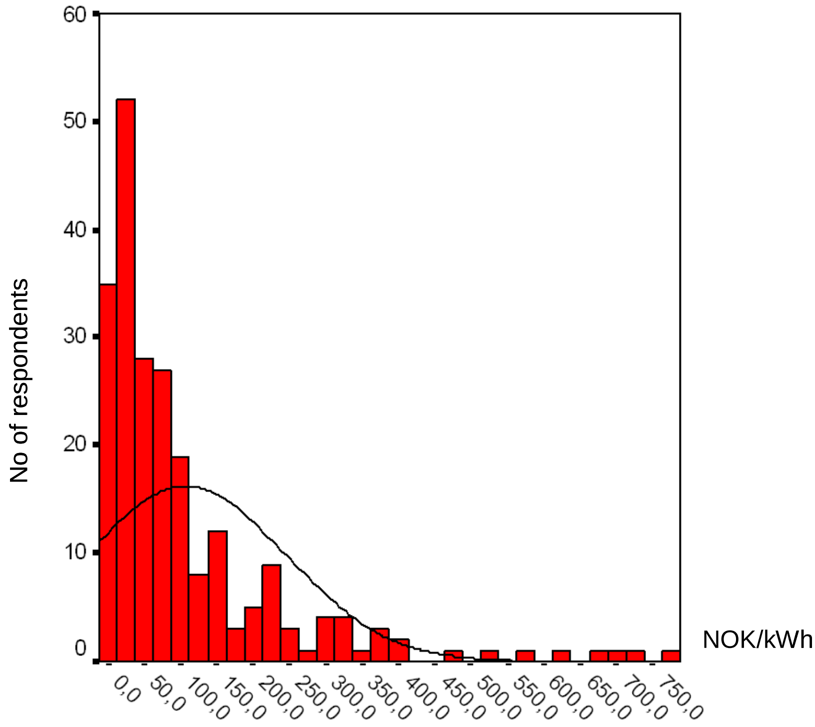

Figure 17: Distribution of normalized cost for 4 hour interruption, Industry (Source: Kjølle et. al 2008)

3.2 COST DATA ESTIMATION

As a result of the preparation and normalization of the survey data, individual normalized cost data are available (per respondent) for different interruption scenarios and voltage disturbances.

The costs of quality of supply problems are a function of the different attributes (such as duration, season, time of day, advance notice and day of the week for interruptions and type of phenomena, frequency, depth or other variables for voltage disturbances) and the different customer characteristics (such as annual kWh usage, kW demand, type of business, type of household, presence of backup equipment, region, etc.). These aspects will at least partly be dealt with in the survey by the grouping of customers and corresponding questionnaires and partly by the normalization.

Cost functions
What kind of cost estimates that should be developed from the survey data depends on the various purposes and applications. For regulatory purposes it is probably sufficient to provide average cost data per sector, however taking into account the most important characteristics of the cost, i.e. those that have significant influence on the total costs.

In recent years it has been customary to estimate mathematical cost functions representing various attributes of the quality of supply problem in question and for example customer characteristics.

These functions are usually denoted as customer damage functions with the general form:

Cost = f [quality problem attributes, customer characteristics]

The customer damage function can be represented by the normalized cost per respondent as given above in (1), for a given duration (for interruption costs) at the reference time *t* of the survey.

For a single customer (e.g. large customers connected to the regional networks or main grid) there is no need to normalize the cost, but still the cost function can be estimated based on survey data.

For combinations of customers in various groups (sectors) it is customary to produce cost functions that can be used for other customers in the same sector but with different levels of demand. For this purpose the individual normalized data can be combined into a sector customer damage function (SCDF) which is determined as average (arithmetic mean) normalized costs based on the individual specific costs from (1) for the respondents belonging to the group, as shown in the following:

$$c_{SCDF}(r,t) = \frac{1}{m}\sum_{i=1}^{m} c_{N,i}(r,t) \quad [\text{€/kWh or kW}] \qquad (3)$$

where

$c_{\text{SCDF}}(r,t)$	=	Sector Customer Damage function (SCDF) for sector *s* for an interruption of duration *r* or voltage disturbance at time *t* [€/kWh or kW]
m	=	Number of respondents in sector *s*

The SCDFs are calculated for long (> 3 min.) and short interruptions (≤ 3 min.) for the different interruption scenarios and voltage disturbances respectively.

The cost estimates in (1) og (3) represent estimates for the surveyed scenarios, i.e. discrete values. The sector customer damage functions for interruption costs may be further represented as continuous cost functions, i.e. the cost in monetary unit per kW as a function of duration. See examples in (Billinton et al. 2001, Kjølle et al. 2008 and Chapter 4.) It is customary to establish these functions by linear interpolation between the discrete surveyed data estimates. If the data are normalized by energy not supplied or annual electricity consumption the discrete data should first be transformed into €/kW-units.

Advance warning
The effect of advance warning (notified interruptions) can be taken into account modifying the cost per interruption with the relative factors provided through the questionnaire for the various customer groups.

Time dependency
The cost estimates presented in the previous sections are given for the reference time of the survey. The reference time is typically assumed to be the worst case (see part A for choice of

scenarios). The surveys of interruption costs usually give information about variation in costs by season, weekdays and time of day. There is little if no information available about time variation in costs related to voltage disturbances. The time dependency in the interruption cost is found to be significant. Examples are given in Chapter 4. This time dependency can be dealt with using the information about deviation in cost in monetary terms from the cost at reference time. An example is given in the following:

This relative variation is used to establish correction factors for the cost of an interruption at any time *j*, determined by the relative variation in cost in hour *h*, on day *d* and in month *m*, assuming that these are independent (which might be questionable). Hence, the cost of an interruption of duration *r* occurring at any time *j* can be determined as follows:

$$\begin{aligned} C_j &= c_j(r)\cdot P_j \qquad (euro) \qquad (4) \\ &= c_{ref}(r)\cdot f_{cj}\cdot P_j \\ &= c_{ref}(r)\cdot f_{Cj}\cdot \frac{P_{ref}}{P_j}\cdot P_j \\ &= c_{ref}(r)\cdot f_{Ch}\cdot f_{Cd}\cdot f_{Cm}\cdot P_{ref} \end{aligned}$$

where

C_j = Interruption cost for an interruption at time *j* (€)
$c_j(r)$ = Normalized cost in €/kW for duration *r* at time *j*
P_j = Interrupted power in kW at time *j*
f_{cj} = Correction factor for normalized cost at time *j*
f_{Cj} = Correction factor for cost (in monetary terms) at time *j*:

$$f_{Cj} = f_{Ch}\cdot f_{Cd}\cdot f_{Cm}$$

In order to determine the time variation f_{cj} in the normalized cost one should take into account the variation in the normalization factor (in this case interrupted power, at reference time, i.e. P_{ref}) as shown above.

It is always important to provide information about the normalization factors used when the cost data are presented to ensure that the right data are used together with the cost estimates for calculation of total costs in monetary terms.

Dispersion and uncertainties

In addition to average cost estimates (arithmetic means) it can be useful to provide the whole distribution of the SCDFs and estimate dispersion measures as mentioned in pervious sections (max. min-values, standard deviations, median, percentiles). This information can be used to figure out how uncertainties in the data and assumptions affect the total costs.

Aggregation of costs to national level

For aggregation purposes a *composite* customer damage function (CCDF) can be estimated, representing an average specific cost for a composition of customer groups, showed by an example in (5):

$$c_{CCDF}(r,t) = \sum_{s=1}^{S} c_{SCDF}(r,t) \cdot W_s \quad [€/kWh] \qquad (5)$$

where

W_s = The sector *s*' proportion of the annual electricity consumption

S = Number of sectors

In the composite customer damage functions each sector's damage functions are weighted by for instance the sectors proportions of the electricity consumption if a measure of energy is used as normalization factor. If the cost estimate is given in monetary units per incident/scenario the number of incidents per sector could be used. The CCDF can thus be used to aggregate the costs of quality of supply problems to the national level.

4 COST RESULTS OF RECENT COST STUDIES AND THE UTILIZATION FOR REGULATION

This chapter presents some results of recent cost studies to give an idea of different results that can be provided through studies on costs due to quality of supply problems. It is important to be aware that it may be difficult to compare cost estimates from different surveys due to country-specific aspects such as differences in customer characteristics and use of electricity, cost level, type and size of normalization factors amongst others. Survey-specific aspects will also give differences in results, for instance due to choice of survey method and reference time for quality of supply scenarios.

4.1 COSTS OF INTERRUPTIONS

Duration

The following figures present cost estimates for different customer groups and survey methods as a function of the duration of the interruption. The cost estimates are usually given as discrete values for the various surveyed scenarios. In the examples the costs are represented by continuous cost functions using linear interpolation. It is important to be aware of the different normalization factors used in different surveys.

Figure 18 and Figure 19 show the normalized costs of interruptions for Households and Business sector in Italy and Households and Industry in Norway respectively, for different durations and methods.

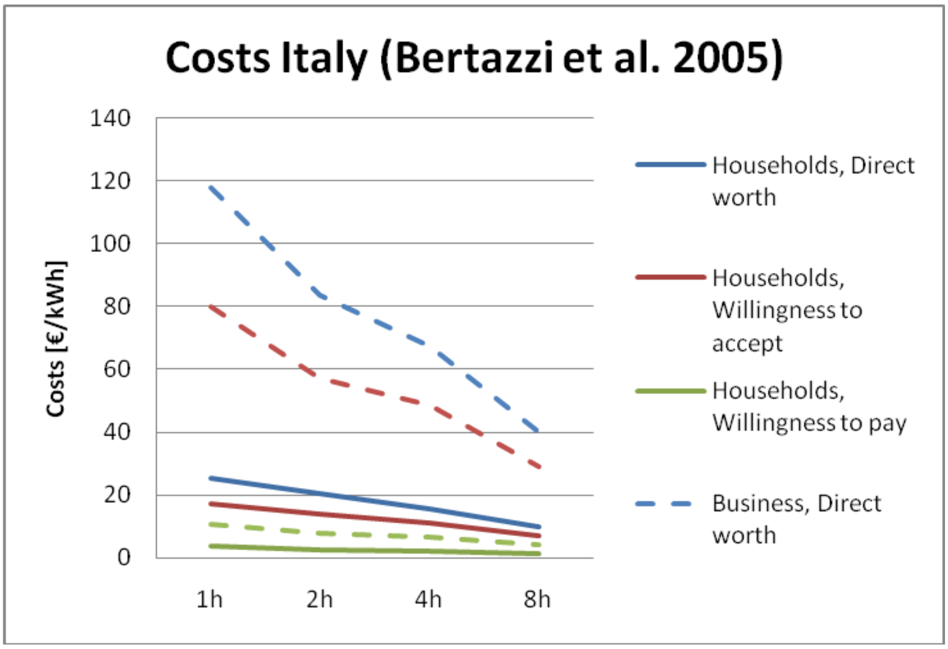

Figure 18: Normalized costs Italy, continuous curves based on discrete values in €/kWh energy not supplied

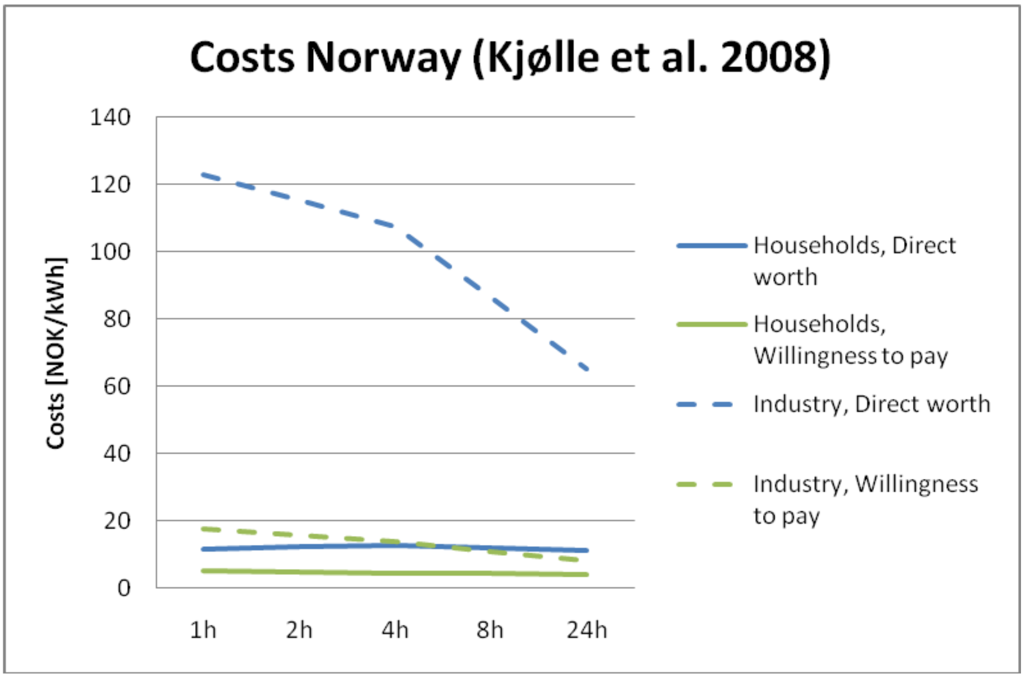

Figure 19: Normalized costs Norway (NOK/kWh energy not supplied), Weekday in January

In both the Italian and the Norwegian surveys the costs were normalized with the energy not supplied. Figure 18 and Figure 19 show that the normalized costs in €/kWh and NOK/kWh energy not supplied respectively are decreasing, even though this correlation is not that significant for the households in Norway.

A comparison between the figures shows that the cost estimates are highly dependent on the chosen survey method. The results yielded willingness to pay estimates significantly lower than the Direct worth estimates, especially for Business sector and Industry respectively. In addition the Italian survey showed a Direct worth estimate which was significantly higher than the willingness to accept estimate. Commonly the willingness to pay estimate is lowest, the willingness to accept is highest and the Direct worth estimate between these two estimates. This observation could be proofed in the Norwegian survey. A possible explanation for the Italian result can be that it is easier to give protest answers to Direct worth questions than to willingness accept questions. Due to cultural reasons many Italians tend to give protest answers as also showed in this survey.

The interruption costs for Households of a survey in Sweden as presented in Figure 20 are stated in total costs per interruption. The absolute costs in SEK/interruption are increasing with longer duration and not decreasing like the values normalized with the energy not supplied shown in the figures above. In addition, Figure 20 shows that the costs are lower for Households when the interruption was planned. In general, the cost for Households is also lower if the interruption occurs during the week compared to the weekend and in winter compared to summer. Furthermore the figure shows that Conjoint analysis revealed lower costs than Contingent valuation.

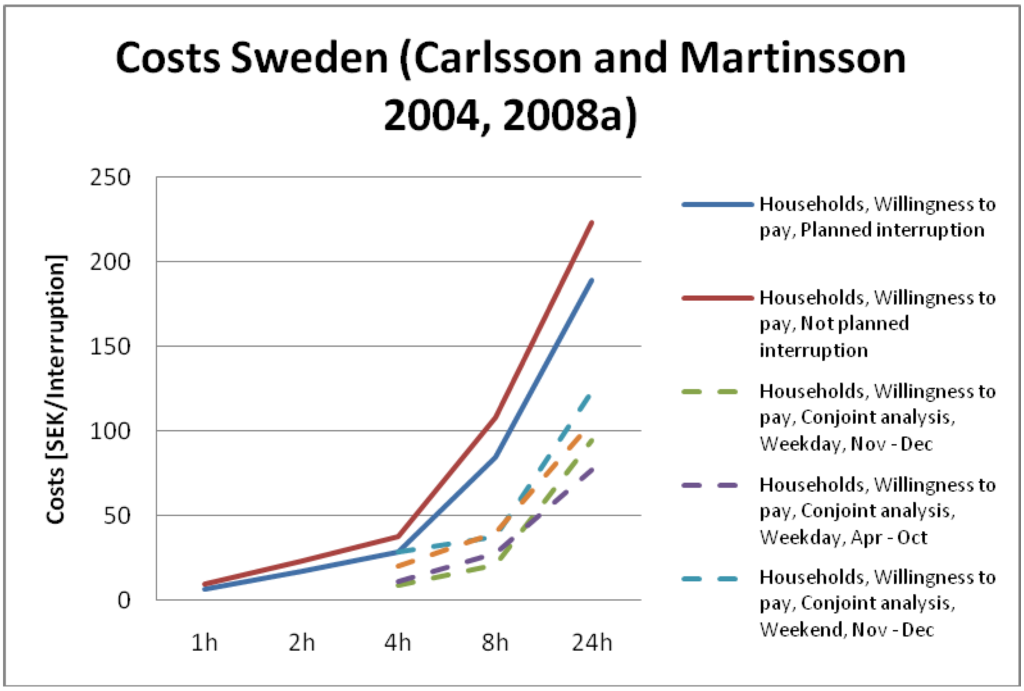

Figure 20: Costs per interruption Sweden (SEK/interruption)

The results of a recent Finnish survey (Figure 21) clearly show the differences of the costs between different customer groups. The costs are normalized with the peak demand in kW which increases with duration similarly with the costs per interruption in Figure 20. The normalized cost estimates from the public sector are quite high. But it has to be considered that the public sector in that survey includes infrastructure services as gas, district heat, water and waste water systems which gave high cost estimates.

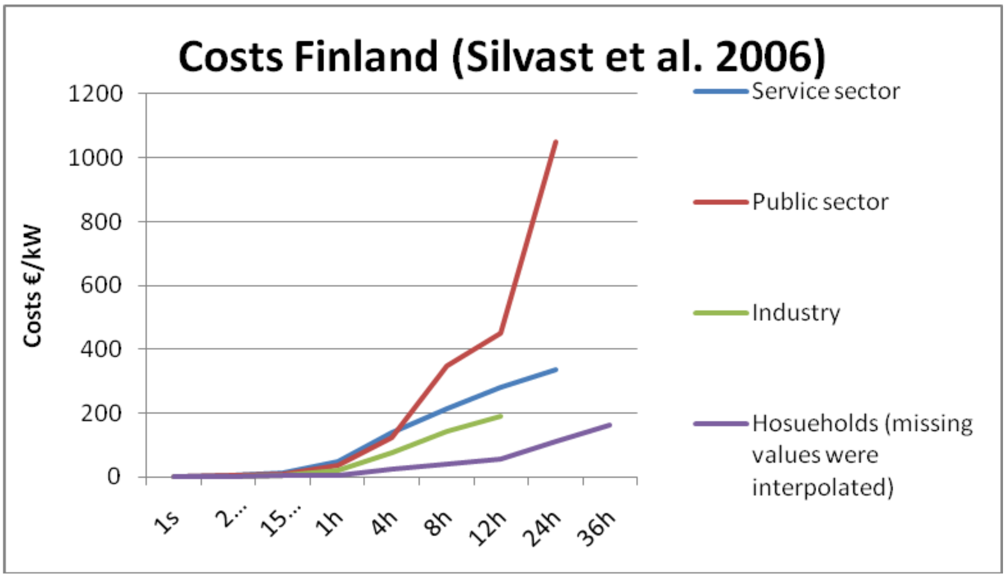

Figure 21: Normalized costs Finland (€/kW peak demand)

Comparison with a recent survey performed in Estonia presented in Figure 22 shows that cost estimates can differ significantly from country to country. The Estonian survey also normalized the costs with the annual peak demand, and used both Contingent valuation and direct cost methods to receive cost estimates from the respondents. All the Estonian cost estimates are significantly lower than in the Finnish survey. Differences in cost estimates are due to country-specific reasons, e.g. the size of normalization factors, but also survey-specific reasons. The time of occurrence (reference time used in the survey) are not always mentioned in the reports making it difficult to compare cost estimates.

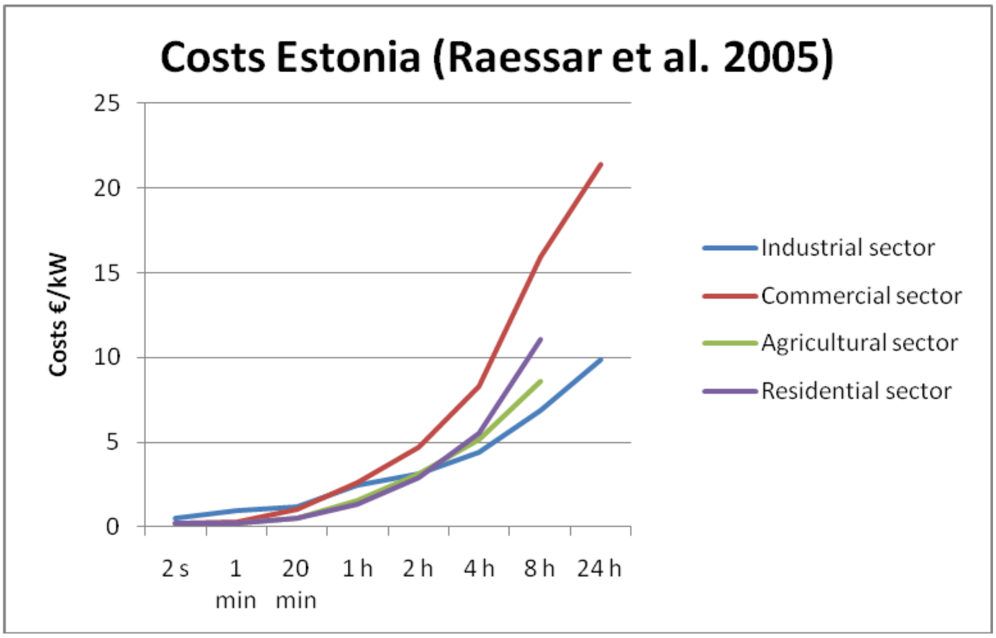

Figure 22: Normalized costs Estonia (€/kW peak demand)

Raessar et al. 2005 tried to compare interruption costs of different countries and converted the costs of different surveys to € (2003) and normalized per kW. The transformation to € were done with two different methods; the exchange rate and purchase power parity estimates. The results were quite different depending on the method and this shows again the challenges of comparing cost estimates from different countries. The results of the comparison can be seen in Figure 23.

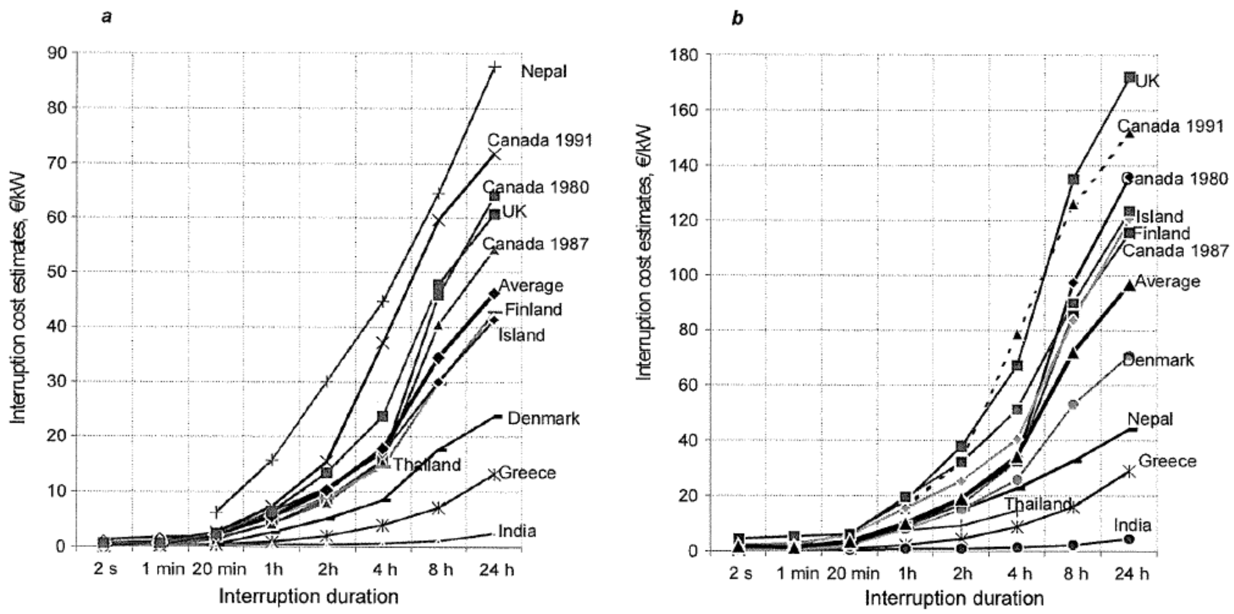

Figure 23: Customer damage functions in €/kW of commercial sector based on (a) exchange rates and (b) purchase power parity estimates. NB! Different scales for interruption cost estimates in (a) vs (b). (Source: Raessar et al. 2005)

Time of occurrence

Costs of electricity interruptions are highly dependent on the time of occurrence. The occurrence is usually described with three attributes; the season, the day of the week, and the time of the day. Households reported in a Swedish survey higher costs on weekends than on weekdays as shown in Figure 24. Surprisingly, the households did not show a clear correlation with the season. The costs were higher in the summer if the interruption occurred on a weekday but lower on the weekend compared to the cold season (see also Figure 20).

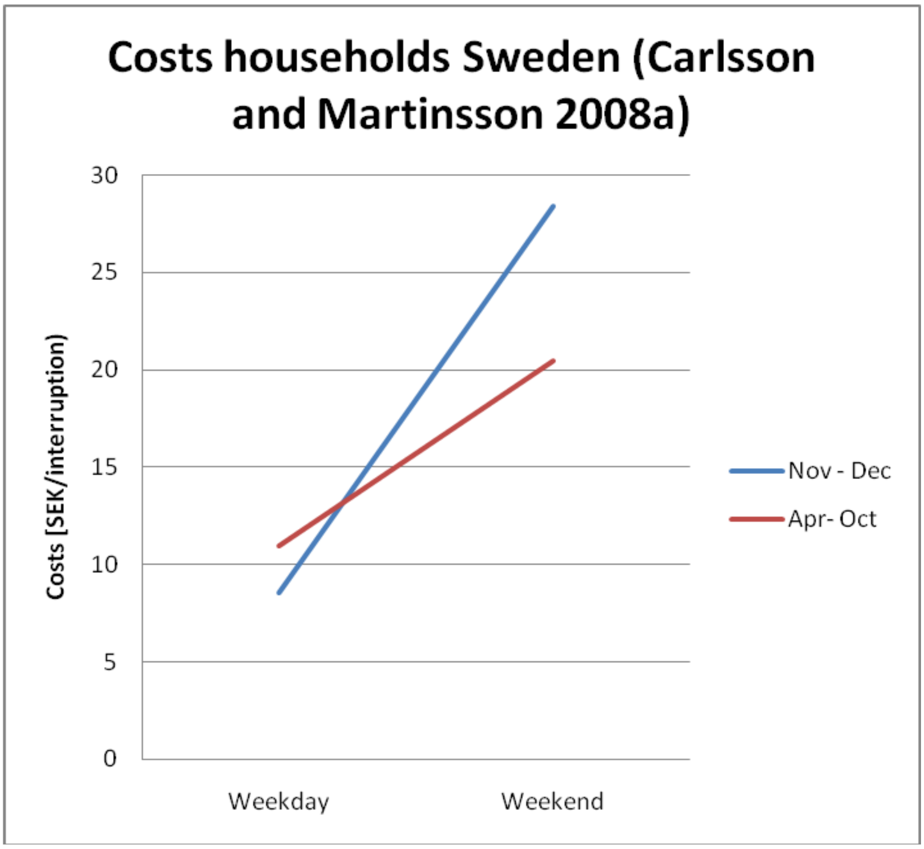

Figure 24: Cost of Households depending on the day of occurrence (SEK/interruption)

In contrast to the Households, Industry, Commercial services, and Public services have the highest cost if an interruption occurs on a working day as shown in Figure 25.

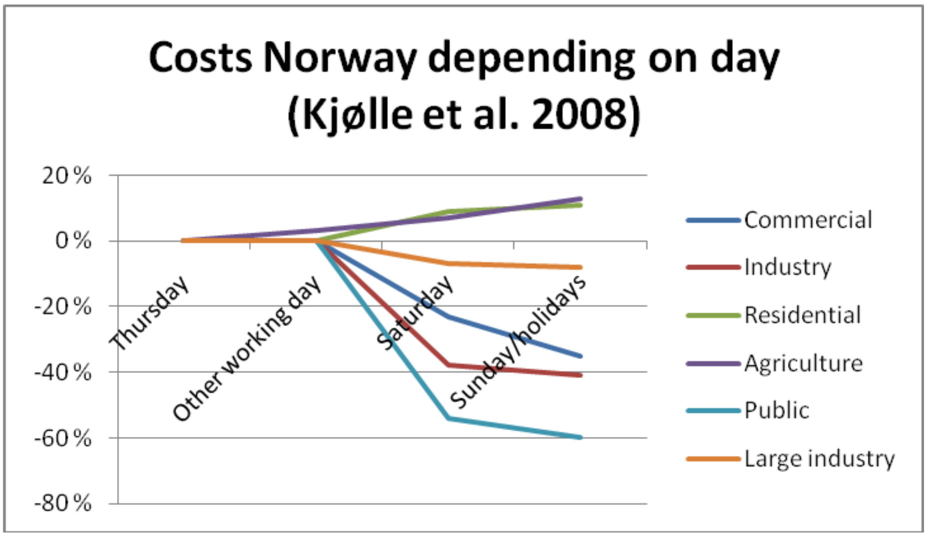

Figure 25: Cost of different customer groups depending on the day of occurrence. % deviation from cost in monetary terms at reference time (Thursday/weekday in January)

The cost of electricity interruption varies also depending on the time of the day. The following figure shows that the costs are highest in the working hours for Industry, Public services and Commercial services. The costs are highest for the households in the evening hours.

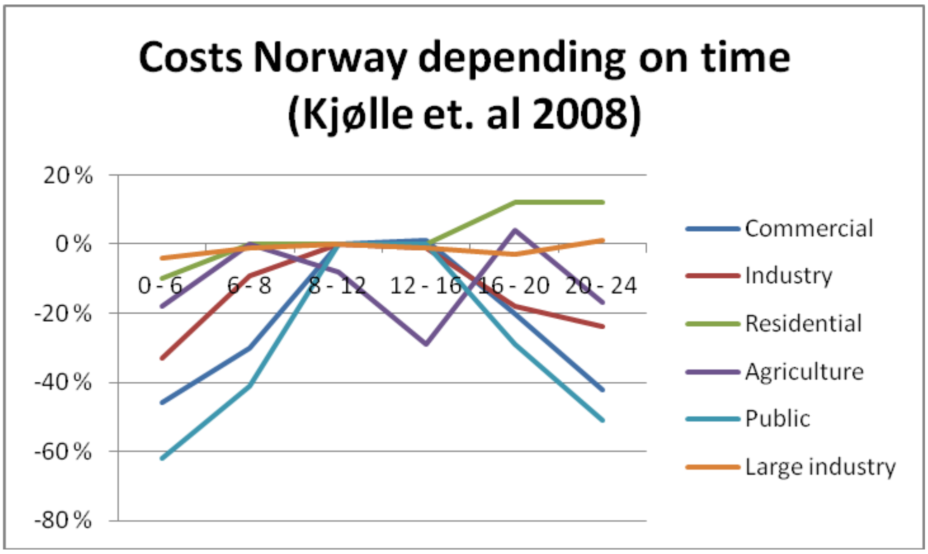

Figure 26: Costs of different customer groups depending on the time of the day. % deviation from cost in monetary terms at reference time

4.2 COSTS OF VOLTAGE DISTURBANCES

In this section cost results of studies which included voltage disturbances are presented for different sectors. No detailed data are available about how costs of voltage disturbances vary with the exact time of occurrence. But it can be expected that the costs show the same trend as the cost caused of electricity interruptions.

A recent Italian study focused exclusively on voltage disturbances. The cost estimates were collected based on different methods. Mainly case studies and journal of events were utilized, but also telephone interviews. The costs were not estimated directly by the respondents. They provided technical and economic data and based on these data the costs of the customers were calculated later. Figure 27 shows the results for different industry sectors. It is important to be aware of the number observations which the cost estimates are based on. Due to the case study approach the sample is relatively small and the results can not be seen as representative for the different sectors.

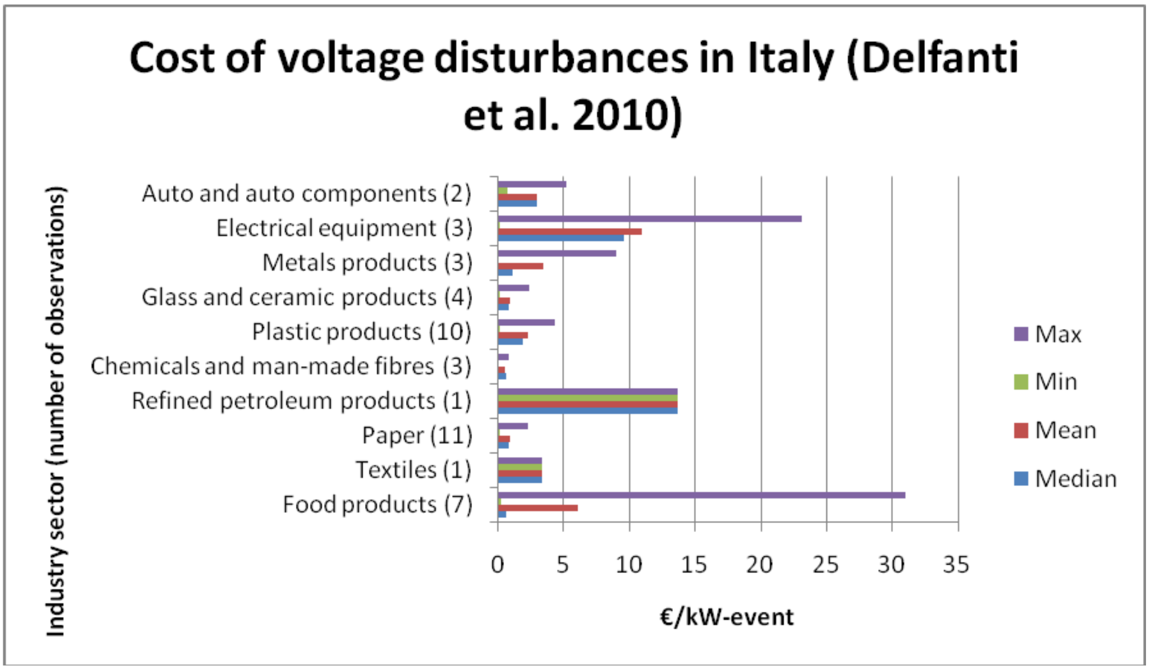

Figure 27: Cost of voltage disturbances in different industry sectors in Italy

A recent Norwegian study included a voltage dip scenario of 1 second and 50 % in the questionnaire about the costs of interruptions. The cost estimates were obtained with the Direct worth method. Figure 28 shows the results of that survey at cost level of January 2002.

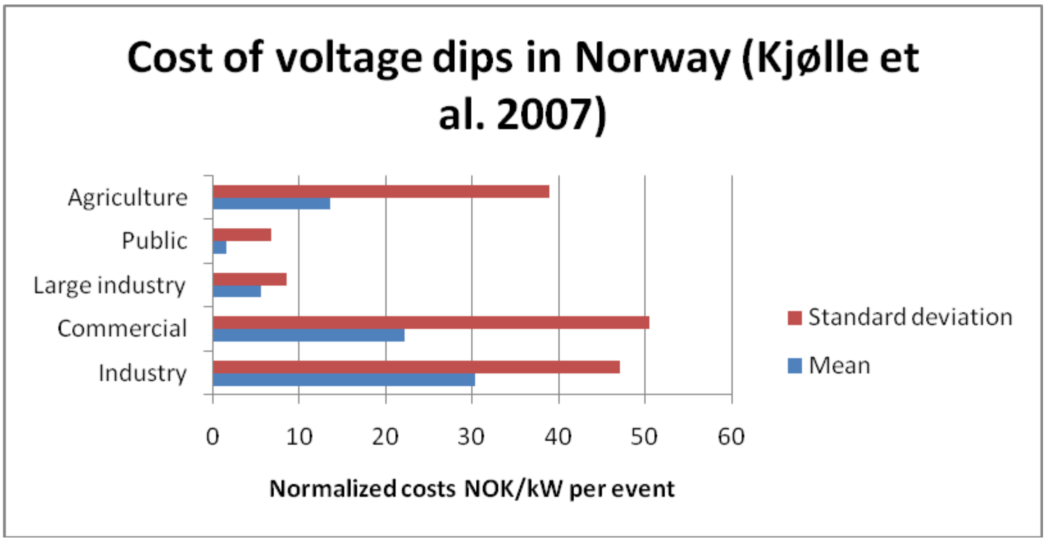

Figure 28: Normalized costs of voltage dips in Norway in NOK/kW demand at reference time

A European study was conducted recently to gain more knowledge about the costs of interruptions and voltage disturbances in Europe. The study was based on survey interviews and web-based answers and included 62 complete interviews. Figure 29 shows the results of this study. The costs due to voltage disturbances were only presented in aggregated numbers referring to a complete year and not per event.

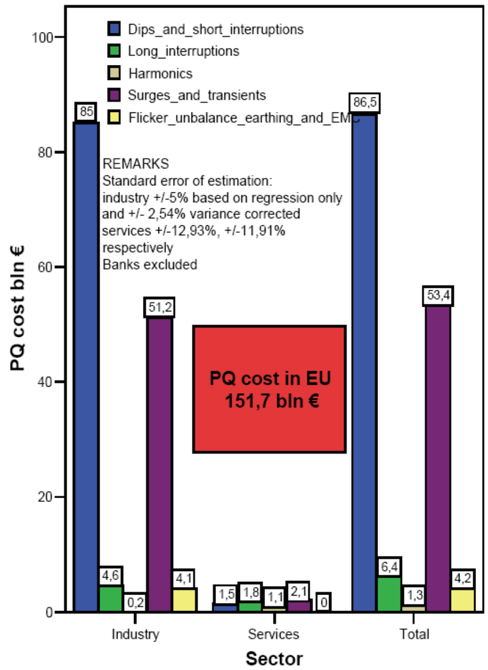

Figure 29: Cost of different power quality phenomena in the EU-25
(Source: Targosz and Manson 2007)

An American study (Layton and Moltner 2005) used choice experiments to assess the cost of interruptions for Households. They included also instantaneous interruptions of 1-2 seconds which can be used as an approximate estimate for voltage disturbance costs. The report presents only the results of the model which were developed with the data of the choice experiment. According to that model instantaneous interruptions do not cause significant cost to an average household.

Two other studies (Tol 2007 and EPPO 2001) included voltage disturbances in their cost assessments of voltage quality problems. Both studies used a Production function approach and reported therefore only aggregated cost numbers. Interruptions and voltage disturbances were not distinguished in these cost numbers and therefore no cost results for voltage disturbances can be presented here.

4.3 DRIVERS OF COST OVER TIME

The costs due to quality of supply problems change over the years because of underlying long term driving forces. It is beneficial to identify these drivers, since it is not possible to conduct a full cost estimation study every year to update costs estimates as such studies are very expensive. Two studies (Vencorp 2009, Sullivan and Sheehan 2000) focused on long term drivers and more information can be found there.

Several principal factors are drivers for the costs over a long time period. The first factor is changes in prices for substitute goods and services for electricity supply, as well as the ability of the customers to purchase them. For example is increased market penetration of backup generators a negative driver for the costs. The second factor is the value of goods and services produced, respective to the direct costs incurred by the customers. In this context, the wage rates are drivers for the costs of the households due to lost time. The third factor is society’s dependency on electricity in general. A higher dependency on electrical devices leads to higher costs.

Several methods are available to adjust cost estimates over time. Vencorp (2009) summarises four principal methods:

- The top-down statistical approach
- Straight-line extrapolation
- General consumer and producer price indices
- Income/economic growth indices.

They recommend the income/economic growth approach.

4.4 UTILIZING RESULTS FOR REGULATION

The following list shows the most common and important types of applications of the cost data which can be directly or indirectly related to quality of supply regulation:

- Taking explicitly account of quality of supply costs in the regulation
    - Incentive based regulation, penalty schemes etc.
- Policies, standards and criteria for quality of supply
    - Guaranteed quality of supply levels, contracts, softened N-1 criterion etc.
- Monitoring quality of supply
    - Actual levels vs standards, expectations etc.
- Planning of power systems
    - Basis for concession applications, justifications of investments etc.
- Operation and maintenance
    - Cost-benefit analyses of quality of supply improving measures, priorities for load shedding, contingency planning, preventive maintenance etc.

Examples are given in the following on utilizing cost data in financial incentive based regulation and aggregation of costs of quality of supply problems to national level respectively.

Incentive based regulation
Network companies are increasingly being subjected to regulatory regimes that explicitly take into account quality of supply costs in incentive based regulation and penalty schemes. One example is the Norwegian incentive based regulation on continuity of supply: CENS (Cost of energy not supplied) where the network companies’ revenue caps are adjusted in accordance with the customers’ interruption costs.

The CENS arrangement entered into force in 2001, but only with regard to long interruptions (> 3 min), based on the mandatory reporting of interruptions for end-users at all voltage levels > 1 kV and a standardized method for estimation of energy not supplied (ENS) as described in Chapter 3 and in (Kjølle et al. 2008). Collection of interruption data and calculation of actual ENS and CENS is made in accordance with the FASIT standard. CENS comprises both notified and non-notified interruptions.

In 2001 and 2002 the customers were divided in two groups with cost rates based on normalized data per energy not supplied from the Norwegian survey performed in the period 1989 – 1991. Since 2003 the customers have been divided in six groups: Industry, Commercial, Large industry, Public sector, Agriculture, Residential, using data from the Norwegian survey in 2001 – 2003. The survey provided cost data normalized with energy not supplied for hypothetical interruptions of 1 minute, 1 hour, 4 hours and 24 hours duration (8 hours for the residential group) referring to a reference time as described in Kjølle et al. 2008. The CENS cost rates were established based on these normalized data as fixed rates for average duration of non-notified interruptions and notified interruptions respectively according to the interruption statistics for the period 1996 – 2001. The CENS cost rates used in the period 2003 – 2006 are shown in the table below. These cost rates were however CPI-adjusted to the actual cost level in 2007 and 2008 respectively.

Table 17: Cost rates used in the CENS arrangement 2003 – 2006*), cost level 2002[24]

Customer group	Non-notified interruption (1,3 h), NOK/kWh ENS	Notified interruption (2,85 h), NOK/kWh ENS	Proportion of the annual electricity consumption (2001)
Industry	66	46	8,9 %
Commercial	99	68	17,0 %
Agriculture	15	10	2,0 %
Residential	8	7	32,8 %
Public sector	13	10	7,7 %
Large industry	13	11	31,6 %

*) In 2007 and 2008, these rates which are referring to 2002 cost-level, were CPI adjusted according to 2007 and 2008 cost-level, respectively

As described above CENS was up to 2009 based on the fixed cost rates (Table 17) for average interruption duration referring to a specific time of the year, week and period of the day (reference time of the survey). To incorporate short interruptions (≤ 3 minutes) and interruption duration in the CENS arrangement from 2009 the cost data revealed by the nationwide survey in 2001 – 2003 were renormalized with interrupted power at the reference time. Interrupted power is defined as the estimated power in kW that would have been supplied at the time of interruption if the interruption did not occur. This resulted in continuous cost functions in NOK/kW as a function of duration still referring to reference time of the survey. These cost functions represent the sector customer damage functions (SCDFs) as defined in part B Chapter 3.

The cost functions provided for the CENS arrangement represent simplified functions based on approximations of those SCDFs. Table 18 gives the cost functions in use from 2009 at reference times given in Table 19 for the different groups.

[24] 1 euro ≈ 8 NOK

Table 18: CENS cost functions in NOK /kW at reference time. r = interruption duration (hours). Cost level 2006**).

Customer group	**Cost function (NOK/kW)**	
	All durations (r) (hours)	
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

**) These cost functions referring to cost level 2006 are CPI-adjusted by Norwegian Water Resources and Energy Directorate to the actual cost level in connection with the calculation of the quality adjustment of the revenue cap.

Table 19: Reference time in the Norwegian survey 2001 - 2003

Customer group	**Reference time**
Agriculture	Thursday in January at 6 a.m.
Residential	Working day in January at 4 p.m.
Industry	Thursday in January at 10 a.m.
Commercial	Thursday in January at 10 a.m.
Public	Working day in January at 10 a.m.
Large industry	Thursday in January at 10 a.m.

The use of cost functions as described above gives a consistent method for handling interruption duration in the CENS arrangement including short and long interruptions. In addition to incorporating short interruptions into the CENS arrangement and taking duration into consideration, CENS was further extended from 2009 to take account of the time of occurrence of interruptions. How this is done is described in Chapter 3 in part B, using information about relative variation in absolute costs as given by Figure 25 and Figure 26.

The old method using fixed cost rates referring to reference time for average interruption duration will occasionally overestimate or underestimate the cost, depending on type of customer, the duration and the time of occurrence of the interruption. This is illustrated by a basic example in (Kjølle et al. 2009).

By this regulatory step from 2009 the network companies not only have incentives to ensure a sufficient level of continuity of supply regarding long interruptions but are additionally provided with incentives to consider the short interruptions and the time dependency in interruption costs in planning, operation and maintenance of the transmission and distribution systems. Taking account of the time dependency will for instance give incentives to perform maintenance work in periods when the interruption cost (in absolute terms) is low. This lays a better foundation for optimizing the continuity of supply, in balancing network costs and the value of continuity as it is seen from the customers' point of view.

Table 20 below gives a summary of the development of the CENS arrangement and the different periods regarding cost rates. The basis for calculation of cost rates as well as the absolute cost per interruption (CENS) is as follows:

- Normalized cost data from nationwide surveys on interruption costs
- Mandatory reporting of notified and non-notified interruptions per delivery (load) point in the medium voltage network (> 1 kV) according to the FASIT standard.
- Load curves for various customer groups (based on load measurements) for the estimation of energy not supplied and interrupted power respectively
- Standardized method for estimation of energy not supplied and interrupted power as defined by the FASIT requirement specification.

Actual levels of CENS and energy not supplied (ENS) are also reported as part of the mandatory monitoring of interruptions.

Table 20: Development of the CENS arrangement in Norway from the introduction in 2001

Period	**2001 – 2002**	**2003 – 2006**	**2007 – 2008**	**2009 -->**
Interruptions included (non-notified and notified)	Long interruptions	Long interruptions	Long interruptions	Long and short interruptions
Customer groups	Business Residential/ agriculture	Industry Commercial Agriculture Residential Public sector Large industry	Industry Commercial Agriculture Residential Public sector Large industry	Industry Commercial Agriculture Residential Public sector Large industry
Cost rates	Fixed for average duration (1996 – 1997) , based on nationwide survey 1989 – 1991, referring to reference time of survey, cost level 1999	Fixed for average duration (1996 – 2001), based on nationwide survey 2001 – 2003, referring to reference time of survey, cost level 2002	Fixed for average duration, based on nationwide survey 2001 – 2003, referring to reference time of survey, CPI-adjusted to actual cost level	Costs as function of duration, based on nationwide survey 2001 – 2003, referring to reference time of survey, CPI-adjusted to actual cost level. Time of occurrence handled using correction factors
Normalization factor	Energy not supplied at reference time	Energy not supplied at reference time	Energy not supplied at reference time	Interrupted power at reference time

Aggregation of costs to national level

An approach for aggregation of the costs to national level is described in Chapter 3. This approach is based on calculation of a composite customer damage function using the sector customer damage functions weighted by the customer sectors proportions of the electricity consumption.

As an example the average cost of long interruptions for non-notified and notified interruptions (with advance warning) are calculated for the Norwegian composition of customer groups based on the CENS cost rates in Table 17. The table also gives each sectors proportion of the annual electricity consumption in 2001 which was about 111 TWh. This gives a weighted average of 31 NOK/kWh for non-notified interruptions and 22,4 NOK/kWh for notified interruptions respectively.

The composite cost rates (weighted normalized costs) can now be used to calculate the total cost of long interruptions. For this purpose we need the total energy not supplied since this parameter was used as the normalization factor for the Norwegian data up to 2009. From the interruption statistics we find that energy not supplied the last 4-5 years has been in the order of 15 GWh per year for Norway as a whole, roughly divided by 30 % due to notified interruptions and 70 % non-notified. This gives:

31 NOK/kWh · 15 000 000 kWh · 0,7 + 22,4 NOK/kWh · 15 000 000 kWh · 0,3 = 426,3 MNOK per year on average

Now, consider the short interruptions (≤ 3 min). Cost rates for short interruptions and voltage dips were estimated from the Norwegian survey 2001 – 2003 given in the table below.

Table 21: Normalized cost rates from Norwegian survey 2001 – 2003. Short interruptions and voltage dips. (Source: Samdal et al. 2006)

	Short interruptions	**Voltage dips**
Customer sector	[NOK/kW]	[NOK/kW]
Industry	17	13
Commercial	19	12
Large industry	6	4
Public sector	1	1
Agriculture	4	4
Residential	2	-

From the interruption statistics for the period 2006 – 2009, we find that delivery points in the distribution network experience approximately 2,8 short interruptions per year. This gives a total cost for the Norwegian customers of approx. 255 MNOK/year. In this calculation the normalized cost figures in Table 21 are weighted with the average load = annual electricity consumption/8760 kW per sector for 2001 and multiplied by the average number of short interruptions.

At last, consider the voltage dips using the cost rates from Table 21. From the Norwegian National Power Quality database we find that the total numbers of voltage dips per year in the distribution network and in the regional network are 63 and 13 respectively in Norway. However, not all of these voltage dips are comparable to the voltage dip-scenario mapped in the survey (50 % reduced voltage in 1 sec). From the database we find that delivery points in the distribution network experience in the range of 3 – 12 such voltage dips/year (varies across customer groups). Using the current cost rate estimates for voltage dips this gives a total cost in the range of 120 – 440 MNOK/year. Again the normalized cost figures for voltage dips in Table 21 are weighted with the average load = annual electricity consumption/8760 kW per sector for 2001and multiplied by the average number of dips according to the range of dips.

A summary of the total annual costs in Norway related to interruptions and voltage dips is given in Table 22.

Table 22: Customers' costs associated with interruptions and voltage dips. 1 euro ≈ 8 NOK.

Long interruptions (> 3 min)	430 MNOK/year (approx.)
Short interruptions (≤ 3 min)	255 MNOK/year (approx.)
Voltage dips	120 - 440 MNOK/year (approx.)
Total	805 - 1125 MNOK/year (approx.)

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6 APPENDIX

6.1 EXAMPLE OF A TYPICAL QUESTIONNAIRE FOR INTERRUPTIONS INCLUDING QUESTIONS ON VOLTAGE DISTURBANCES FOR HOUSEHOLDS

A Characteristics of the customer	
Region	
1	In which municipality is the household located?
2	Do you live in a town or a village?
Information about the household	
3	How many residents are included in the household? • Baby (< 3 years): • Children (3 – 19 years): • Adults (20 – 67): • Seniors (> 67 years):
4	Type of housing? • Detached house: • Semi-detached house: • Row house: • Apartment: • Other:
5	What is the size and the building year of the apartment/house? • Size [m2]: • Year:
6	What is the yearly income of the household? • Income [€]:
7	Does the household includes: • Sick bed resident? • Medical equipment? • Home office?
Electricity consumption	
8	Total electricity consumption in the last year [kWh]?
9	What was your electricity bill in the last year [€]?
Experiences with interruptions and voltage disturbances	
10	How many interruptions has the household experienced in the last year? Number: _______ ☐ I do not know

11	Below possible consequences of voltage disturbances are listed. Has your household suffered some of these phenomena over the past year? • Damage to electrical equipment and appliances • Malfunction of electrical equipment including lighting control equipment • Reduced light output • Poor lighting quality (flicker) • Short life time of light bulbs • Tripping of computers and other electrical equipment
Customer satisfaction	
12	The number of interruptions experienced by the household in the last year is: • very small • small • moderate • high • very high
12	The information I get from the electricity company when an interruption occurs is: • very bad • bad • acceptable • good • very good

B Cost estimation scenarios	
Reference scenario	
14	If an electricity interruption occurs with the following characteristics, what would be the costs for your household? Season: January Day of week: working day Time of day: 4pm Duration: 4 hours (not known in advance) Warning: no advance warning What consequences would affect your household? Can you specify the discomfort for each of the consequence categories (not at all, little, large, very large): • Lost food in freezer/refrigerator • Damaged equipment • Lost computer data • Reprogramming of electronic devices • Uncomfortable indoor temperature • No light • No possibility to cook • Interruption of leisure activities • Home office / PC can not be used • Higher risk of accidents • Higher risk of being exposed to burglary

15	What are your costs due to an interruption as described in question 14 [€]?	
16	Assume that a reserve electricity supply could be available, which can supply the household with electricity during the interruption. You would only be billed for the use of the reserve electricity supply for the time of the interruption. How much would you pay for such a service in the described interruption scenario? Willing to pay for the service [€]:	
17	Assume that the network company informs you about an interruption, just before the interruption will occur (no time for preventative actions). Your household can choose whether it will accept the power interruption and simultaneously receives a financial compensation, or whether the power supply is not switched off and you may continue to use electricity as before. What is the minimum amount of compensation you will need to accept a power interruption as described? The minimum compensation is [€]:	
Changes in cost (related to the reference scenario or by specifying new scenario)		
18	What are your costs due to an interruption as described in question 14 for different interruption durations? • Duration 1 hour [€]: • Duration 2 hours [€]: • Duration 4 hours [€]: • Duration 8 hours [€]:	
19	Can you specify the costs relative to the reference scenario if the interruption occurs in another season [%]?	
	A	Spring:
	B	Summer:
	C	Autumn:
20	Can you specify the costs relative to the reference scenario if the interruption occurs at another day [%]?	
	A	Saturday:
	B	Sunday/holiday:
21	Can you specify the costs relative to the reference scenario if the interruption occurs at another time [%]?	
	A	Day (7am – 5pm):
	B	Evening (5pm – 12pm):
	C	Night (0am – 7am):
22	If an electricity interruption occurs with the following characteristics, what would be the costs for your household? • Season: July • Day of week: working day • Time of day: 10am • Warning: no advance warning	
Incentive		
23	The respondent can win lottery tickets, if the form is filled out complete. Please fill in the contact address, if you wish to participate in the drawing of the lottery tickets. Contact address:	

6.2 EXAMPLE OF A TYPICAL QUESTIONNAIRE FOR INTERRUPTIONS INCLUDING QUESTIONS ON VOLTAGE DISTURBANCES FOR INDUSTRY

A Characteristics of the customer	
Region	
1	In which municipality is the business located?
2	Is it located in a rural or urban area?
Information about the company	
3	What do you manufacture? • Food products • Beverages • Tobacco products • Textiles • Wearing apparel • Leather and related products • Products of wood, except furniture • Paper products • Printing and reproduction of recorded medias • Refined petroleum products • Chemical products • Pharmaceutical products • Plastic products • Non-metallic mineral products • Basic metals • Fabricated metal products, except machinery and equipment • Computer, electronic and optical products • Electrical equipment • Machinery and equipment • Motor vehicles • Other transport equipment • Furniture • Repair and installation of machinery and equipment • Other manufacturing
4	How many employees do you have?
5	What was the turnover in the last year [€]?
6	How many shifts do you have?
7	Has your company undertaken actions to reduce the consequences of interruptions/voltage disturbances? • None • Contacted grid company

	• Installation of an emergency power unit • Installation of overvoltage protection • Installation of overharmonic filter • Installation of phase compensating equipment • Installation of UPS • Insurance (disaster, production)
8	What are the yearly expenses for these actions?
Electricity consumption	
9	Total electricity consumption in the last year [kWh]?
10	What was your electricity bill in the last year [€]?
Experiences with interruptions and voltage disturbances	
11	How many interruptions has your company experienced during the last year?
12	Below possible consequences of voltage disturbances are listed. Has your company suffered some of these phenomena over the last year? • Malfunction in computer systems • Problems with starting electric motors • Malfunction in process control systems • Electric motors disconnected from electricity network by the motor protection • Short life time of light bulbs • Electrical equipment gets hot
Customer satisfaction	
13	The number of interruptions experienced by your company in the last year is: • very small • small • moderate • high • very high

B Cost estimation scenarios	
Reference scenario	
14	If an electricity interruption occurs with the following characteristics, what would be the costs for your company? Duration: 1 hour Season: January Day of week: working day Time of day: 10am Warning: no advance warning

	A	Lost production (minus savings) [€]:
	B	Costs for making up production (overtime, etc.) [€]:
	C	Costs for delayed delivery (fines, etc.) [€]:
	D	Damage to raw materials and finished products [€]:
	E	Damage to equipment [€]:
	Sum of all costs [€]:	
15	Has the interruption other non-monetary consequences? • Danger for person safety • Document safety • Crimes/burglary • Spill over effects to customers • Inconvenience • Pollution to the environment	
Changes in cost (related to the reference scenario or by specifying new scenarios)		
16	Can you specify the total costs for the following scenarios based on the reference scenario for different durations? Voltage reduced with 50 % for 1 sec	
	A	Lost production (minus savings):
	B	Costs for making up production (overtime, etc.):
	C	Costs for delayed delivery (fines, etc.):
	D	Damage to raw materials and finished products:
	E	Damage to equipment:
	Sum of all costs [€]:	
	Interruption for 1 min	
	A	Lost production (minus savings):
	B	Costs for making up production (overtime, etc.):
	C	Costs for delayed delivery (fines, etc.):
	D	Damage to raw materials and finished products:
	E	Damage to equipment:
	Sum of all costs [€]:	
	Interruption for 1 hour	
	A	Lost production (minus savings):
	B	Costs for making up production (overtime, etc.):
	C	Costs for delayed delivery (fines, etc.):
	D	Damage to raw materials and finished products:
	E	Damage to equipment:
	Sum of all costs [€]:	
	Interruption for 4 hours	
	A	Lost production (minus savings):
	B	Costs for making up production (overtime, etc.):
	C	Costs for delayed delivery (fines, etc.):
	D	Damage to raw materials and finished products:
	E	Damage to equipment:
	Sum of all costs [€]:	

	Interruption for 24 hours		
	A	Lost production (minus savings):	
	B	Costs for making up production (overtime, etc.):	
	C	Costs for delayed delivery (fines, etc.):	
	D	Damage to raw materials and finished products:	
	E	Damage to equipment:	
	Sum of all costs [€]:		
17	Can you specify the total costs relative to the reference scenario if the interruption occurs in another season [%]?		
	A	Spring:	
	B	Summer:	
	C	Autumn:	
18	Can you specify the total costs relative to the reference scenario if the interruption occurs at another day [%]?		
	A	Another working day:	
	B	Saturday:	
	C	Sunday/holiday:	
19	Can you specify the total costs relative to the reference scenario if the interruption occurs at another time [%]?		
	A	Day (7am – 5pm):	
	B	Evening (5pm – 12pm):	
	C	Night (0am – 7am):	
Advance warning			
20	If an electricity interruption of 4 hrs will occur and you are given advance warning 2 hrs before, how much will your costs be reduced compared to the reference scenario in question 16 [%]?		
21	Estimate the required warning time that the company needs to reduce the cost of an interruption? • Less than 1 hour • 1 – 4 hours • 5 – 8 hours • 8 – 24 hours • 2 days • More than 2 days • Costs can not be reduced		
Results			
22	The results of the survey can be sent to you, if you are interested. In that case, please fill out the contact address. • Contact address:		

Willingness to pay and accept questions similar to those for Households in appendix 6.1 can be included.

6.3 NACE

		Customer group
A AGRICULTURE, FORESTRY AND FISHING		
	01 Crop and animal production, hunting and related service activities	Industry (Agriculture)
	02 Forestry and logging	Industry
	03 Fishing and aquaculture	Industry
B MINING AND QUARRYING		
	05 Mining of coal and lignite	Industry
	06 Extraction of crude petroleum	Industry
	07 Mining of metal ores	Industry
	08 Other mining and quarrying	Industry
	09 Mining support service activities	Industry
C MANUFACTURING		
	10 Manufacture of food products	Industry
	11 Manufacture of beverages	Industry
	12 Manufacture of tobacco products	Industry
	13 Manufacture of textiles	Industry
	14 Manufacture of wearing apparel	Industry
	15 Manufacture of leather and related products	Industry
	16 Manufacture of wood and products of wood and cork; except furniture; manufacture of articles of straw and plaiting materials	Industry
	17 Manufacture of paper and paper products	Industry
	18 Printing of reproduction of recorded media	Industry
	19 Manufacture of coke and refined petroleum products	Industry
	20 Manufacture of chemicals and chemical products	Industry
	21 Manufacture of basic pharmaceutical products and pharmaceutical preparations	Industry
	22 Manufacture of rubber and plastic products	Industry
	23 Manufacture of other non-metallic mineral products	Industry
	24 Manufacture of basic metals	Industry
	25 Manufacture of fabricated metal products, except machinery and equipment	Industry
	26 Manufacture of computer, electronic and optical products	Industry
	27 Manufacture of electrical equipment	Industry
	28 Manufacture of machinery and equipment n.e.c.	Industry
	29 Manufacture of motor vehicles, trailers and semi-trailers	Industry
	30 Manufacture of other transport equipment	Industry
	31 Manufacture of furniture	Industry
	32 Other manufacturing	Industry

	33 Repair and installation of machinery and equipment	Industry
D ELECTRICITY,GAS,STEAM AND AIR CONDITIONING SUPPLY		
	35 Electricity, gas, steam and air conditioning supply	Industry
E WATER SUPPLY;SEWERAGE,WASTE MANAGEMENT AND REMEDIATION ACTIVITIES		
	36 Water collection, treatment and supply	Infrastructure
	37 Sewerage	Infrastructure
	38 Waste collection, treatment and disposal activities; materials recovery	Industry
	39 Remediation activities and other waste management services	Industry
F CONSTRUCTION		
	41 Construction of buildings	Industry
	42 Civil engineering	Industry
	43 Specialised construction activities	Industry
G WHOLESALE AND RETAIL TRADE;REPAIR OF MOTOR VEHICLES AND MOTORCYCLES		
	45 Wholesale and retail trade and repair of motor vehicles and motorcycles	Commercial services
	46 Wholesale trade, except of motor vehicles and motorcycles	Commercial services
	47 Retail trade, except of motor vehicles and motorcycles	Commercial services
H TRANSPORTATION AND STORAGE		
	49 Land transport and transport via pipelines	Infrastructure
	50 Water transport	Infrastructure
	51 Air transport	Infrastructure
	52 Warehousing and support activities for transportation	Commercial services
	53 Postal and courier activities	Commercial services
I ACCOMMODATION AND FOOD SERVICE ACTIVITIES		
	55 Accommodation	Commercial services
	56 Food and beverage service activities	Commercial services
J INFORMATION AND COMMUNICATION		
	58 Publishing activities	Commercial services
	59 Motion picture, video and television programme production, sound recording and music publishing activities	Commercial services
	60 Programming and broadcasting activities	Commercial services
	61 Telecommunications	Infrastructure
	62 Computer programming, consultancy and related activities	Commercial services
	63 Information service activities	Commercial services

K FINANCIAL AND INSURANCE ACTIVITIES		
	64 Financial service activities, except insurance and pension funding	Commercial services
	65 Insurance, reinsurance and pension funding, except compulsory social security	Commercial services
	66 Activities auxiliary to financial services and insurance activities	Commercial services
L REAL ESTATE ACTIVITIES		
	68 Real estate activities	Commercial services
M PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES		
	69 Legal and accounting activities	Commercial services
	70 Activities of head offices; management consultancy activities	Commercial services
	71 Architectural and engineering activities; technical testing and analysis	Commercial services
	72 Scientific research and development	Commercial services
	73 Advertising and market research	Commercial services
	74 Other professional, scientific and technical activities	Commercial services
	75 Veterinary activities	Commercial services
N ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES		
	77 Rental and leasing activities	Commercial services
	78 Employment activities	Commercial services
	79 Travel agency, tour operator and other reservation service and related activities	Commercial services
	80 Security and investigation activities	Commercial services
	81 Services to buildings and landscape activities	Commercial services
	82 Office administrative, office support and other business support activities	Commercial services
O PUBLIC ADMINISTRATION AND DEFENCE;COMPULSORY SOCIAL SECURITY		
	84 Public administration and defence; compulsory social security	Public services
P EDUCATION		
	85 Education	Public services
Q HUMAN HEALTH AND SOCIAL WORK ACTIVITIES		
	86 Human health activities	Public services / Commercial services
	87 Residential care activities	Public services / Commercial services
	88 Social work activities without accommodation	Public services / Commercial services
R ARTS, ENTERTAINMENT AND RECREATION		
	90 Creative, arts and entertainment activities	Commercial services
	91 Libraries, archives, museums and other cultural activities	Public services
	92 Gambling and betting activities	Commercial services
	93 Sports activities and amusement and recreation	Commercial services

	activities	
S OTHER SERVICE ACTIVITIES		
	94 Activities of membership organisations	Commercial services
	95 Repair of computers and personal and household goods	Commercial services
	96 Other personal service activities	Commercial services
T ACTIVITIES OF HOUSEHOLDS AS EMPLOYERS;UNDIFFERENTIATED GOODS- AND SERVICES-PRODUCING ACTIVITIES OF HOUSEHOLDS FOR OWN USE		
	97 Activities of households as employers of domestic personnel	Households
	98 Undifferentiated goods-and services-producing activities of private households for own use	Households
U ACTIVITIES OF EXTRA TERRITORIAL ORGANISATIONS AND BODIES		
	99 Activities of extraterritorial organisations and bodies	Commercial services

6.4 LIST OF ABBREVIATIONS

CEER	Council of European Energy Regulators
CENS	Cost of energy not supplied
CPI	Consumer Price Index
E	Expected cost value
ENS	Energy not supplied
FASIT	Norwegian standard for collecting continuity of supply data
LPG	Liquefied petroleum gas
NACE	Statistical classification of economic activities in the European community
NOAA	National Oceanic and Atmospheric Administration
OP	Option price
OV	Option value
r.m.s.	Root mean square
SCDF	Sector customer damage function
CCDF	Composite customer damage function
THD	Total harmonic distortion factor
ToR	Terms of reference
WTA	Willingness to accept
WTP	Willingness to pay

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