RAIN PROJECT

Security Sensitivity Committee Deliverable Evaluation

Deliverable Reference	**D 4.3**
Deliverable Name	**Social impact of failures in E & TC infrastructures**
Contributing Partners	**Grupo AIA**
Date of Submission	**November 2015**

The evaluation is:

- **The content is not related to general project management**
- **The content is not related to general outcomes as dissemination and communication**
- **The content is related to critical infrastructure vulnerability or sensitivity**
- **The content is publicly available or commonly known**
- **The content does not add new information on vulnerabilities, sensitivities or incident scenario's on specific objects or transport systems or in general**
- **There are no uncertainties that might need to contact the NSA**

Diagram path 1-2-3-4-5.1-5.2-9. Therefor the evaluation is Public.

Decision of Evaluation	**Public**	~~**Confidential**~~
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Social impact of failures in E & TC infrastructures

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Table of Contents

1 Executive Summary

This report represents the final logical step for the risk assessment in Electric and telecommunication infrastructures: D4.1 and D4.2 focused on identification of critical elements and their relevant meteorological threats, and the different ways protecting or mitigating the effects. Here, the aim is to quantify the effect of such extreme weather events, and in particular from a social point of view. First, the standard metrics are reviewed (coming from engineering or economic criteria) quantifying in physical or monetary units the consequences of outages. These are the ones used in national regulations. Then, the social dimension is explored: separating different types of consumer and the different channels involved, related to the specific human activities affected. Some European examples are presented. One of the objectives of this document is to help policy makers to consider impact indicators that effectively measure the human dimension.

2 Introduction

One could think that increasing energetic efficiency of all kind of devices would lead to a reduction on the global demand. The *electrical version* of the Jevons paradox, the Khazzoom-Brookes postulate (Saunders, 1992) and references therein, states that even if the energy efficiency of single devices increases considerably, the global demand of power might increase as well. Applying neoclassical growth theory to the Khazzoom-Brookes postulate, Saunders found that an improvement in efficiency will increase the power demand. In particular, e*nergy efficiency gains can increase energy consumption by two means: by making energy appear effectively cheaper than other inputs; and by increasing economic growth, which pulls up energy use* (Saunders, 1992). Therefore, the dependence of modern societies on **electric power** has increased and keeps increasing. In addition, access to electricity is fundamental in supporting most of other critical infrastructures, from water and sewage systems to railroads and transportation (Hämmerli, Svendsen, & Lopez, 2012).

Another explicit interconnection exists between electricity and **telecommunications networks**. In the recent years, dependency between both networks has raised also: digitalization of telephone services, that evolved towards the telecom networks used nowadays, implied a rise in power consumption by the different elements in these networks from the central offices to the end user apparatus; sharing distribution infrastructures, e.g. inclusion of optical fiber cables in high voltage overhead power lines (REE - RED ELECTRICA DE ESPAÑA).

Moreover, and of interest of the present document, the International Panel on Climate Change[1] (IPCC) has warned, in their fifth assessment report (Pachauri & Meyer, 2014),about the *increasing potential impacts to infrastructure systems, built environment and ecosystem services in urban areas brought by **changing climate risks***, as pointed out in (Hasan & Foliente, 2015).

Consequently, it becomes of capital importance to be able to assess the impact of service disruptions in electrical and telecommunication networks. In particular, it is fundamental for:

- Determining the **investments** (which and where) by the different providers in order to improve **quality** and **continuity** of the service.
- Helping regulatory agencies and policy makers to define **regulations** to the quality and continuity of the service and protect the final users.

[1] Established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988. http://www.ipcc.ch/

- Being able to **compare** the effects among various situations: geographical area, population, particular services, season of the year, time of the day, etc.
- Measuring **trends**, especially important in order to adapt the infrastructures to the effects of climate change, for instance.

Within the RAIN project, *quantifying the social impact of failures in E & TC infrastructures* is one of the key parts of the evaluation assessment framework described in the deliverable D4.2. It is required as an input for the modeling: the framework will be able to answer questions like "how much the impact of a extreme weather event can be reduced if this or that preventive (or mitigation) measures are taken?"

The effects of outages (either related to extreme weather events or not) are usually quantified in economical and engineering terms. As described in sections *Reliability indices and governmental regulations* and *Value of Lost Load*, the number of affected population and duration of an outage or the Value of Lost Load (VoLL) are the most common indices used. These measurements give information about the disruption and are defined quite clearly. However, they do not consider some of the effects on the population: e.g. it is not the same not supplying 4 MWh to a hospital, a factory, a residential area, or to a public transportation system like a railroad.

Governments, through the National Regulatory Agencies (NRA), or international agencies like ENISA[2] in Europe establish a number of regulations to ensure that the different companies provide quality, uninterrupted service, and to protect the final users of these services. They are also interested in assessing the effects of possible or actual telecommunications or power disruptions on the population. This way, preventive or mitigation measures can be considered. Nevertheless, it is not an easy task since standard proceedings are not defined. Different approaches are proposed by economists working in the field, but no consensus has been reached yet.

Especially difficult to model and assess are the social impacts. A qualitative approach is provided in section Social Effects and is summarized in Table *4*. Socioeconomic effects of electrical and telecommunication failures are categorized by user group. Usually three profiles are distinguished: businesses, community service providers, and individuals.

In addition, it is not straightforward to compare economical measurements among different countries if a normalization factor is not considered. Particularly difficult is to compare the social impact in different countries or regions because of its ambiguous definition.

[2] The European Union Agency for Network and Information Security (ENISA), https://www.enisa.europa.eu/

Comparing the assessment of the effects of an electrical blackout or a telecommunications network outage, in both cases one of the main measurement is the duration of disruption of the service in relation to the number of affected users. However, while in the electric networks a number of indices are well defined to weight the importance of a blackout, in the telecommunications networks these indices are still to be established. The latter is, in part, due to the fast evolution and change in the technologies used and the economic sectors related to them (digital economy, e-commerce, etc.) that are difficult to assess.

The document is structured as follows: first section contains a compilation of the defined reliability indices and governmental regulations affecting the electrical and telecommunication sectors. Then, social effects of disruptions of the service are exposed qualitatively in Social effects, and quantitative approaches presented in Measuring social impact. This deliverable ends with some examples of assessment of power outages in three European countries, and the conclusions of the work.

3 Reliability indices and governmental regulations

3.1 Electric sector

Transmission network outages and performance monitoring approaches

Electricity networks are divided according to their voltage level in transmission (for High Voltage HV) and distribution networks (for Medium or Low Voltage MV/LV). Substations convert their voltage levels using distribution/step-up/autotransformers and auxiliary equipment to transport the produced energy to the points of consumption. Both producers and consumers, as well as the latest entities of prosumers (physical entities that produce and consume energy in the modern decentralized distribution networks), consist the 'load points' / 'connection points' / 'customers' of the electricity networks. In the case that transmission and distribution networks are studied separately, the network interconnections are represented as 'connection points'.

Several TSOs have formed detailed procedures for monitoring performance, which vary on several issues, such as: the period of analysis, the outage data processing and analysis, and the definition of indices. Performance monitoring metrics focus on providing TSOs an incentive to improve network availability and reliability. Additionally, regulatory authorities promote network performance monitoring and in many cases apply penalties or rewards for lower / higher level than prescribed.

In addition to its role as the Transmission Owner in England and Wales, National Grid Electricity Transmission (NGET) is Great Britain's System Operator (GBSO). In accordance with its Transmission Licence, NGET, as NETSO, is required by the Gas and Electricity Markets Authority OFGEM, to report National Electricity Transmission System performance in terms of availability, system security and the quality of service. A specific data reporting template is described in the RIIO-T1 regulatory instructions that involves detailed definitions for faults and failures for each transmission asset category (cables, auxiliary equipment) and several network performance indices are calculated and presented in the yearly "National Electricity Transmission System Performance Report" published by the NGET (National Grid, 2011), (OFGEM, 2012).

In this report, a *circuit* is defined as equipment on the transmission system, e.g. overhead line, transformer or cable which either connects two bussing points or connects two or more circuit breakers/disconnectors, excluding busbars. System availability is reduced whenever a circuit is taken out of operation for either planned purposes or as a result of a fault. Planned outages are required for system construction and new user connections in addition to the maintenance necessary to retain a high level of system reliability to ensure that licence standards of security are met (National

Grid, 2011)**¡Error! No se encuentra el origen de la referencia.**, (OFGEM, 2012)**¡Error! No se encuentra el origen de la referencia.**. System availability Figure 1 is calculated by the formula:

$$System\ availability = \frac{The\ sum\ for\ all\ circuits\ of\ hours\ available}{(No.of\ circuits)\ x\ (No.of\ hours\ in\ period)} \times 100\%$$

Winter Peak Availability is defined as the average System Availability over the three months of December, January and February.

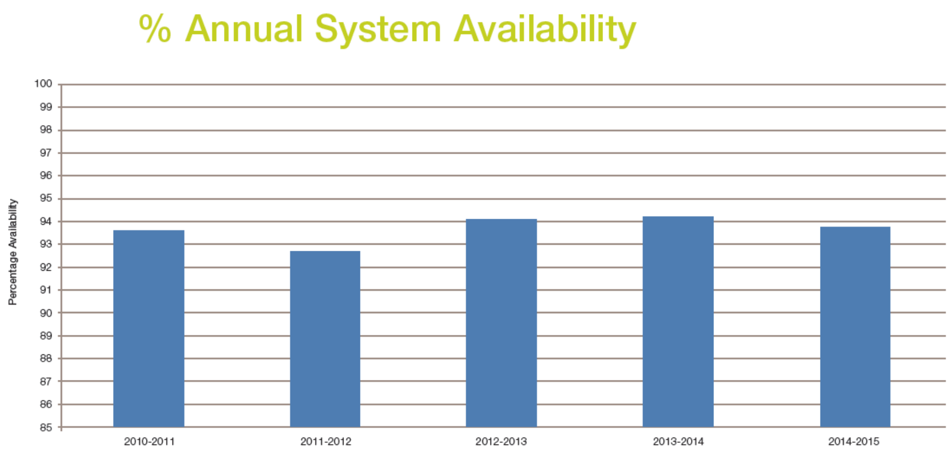


Figure 1. Annual system availability for England and Wales Network

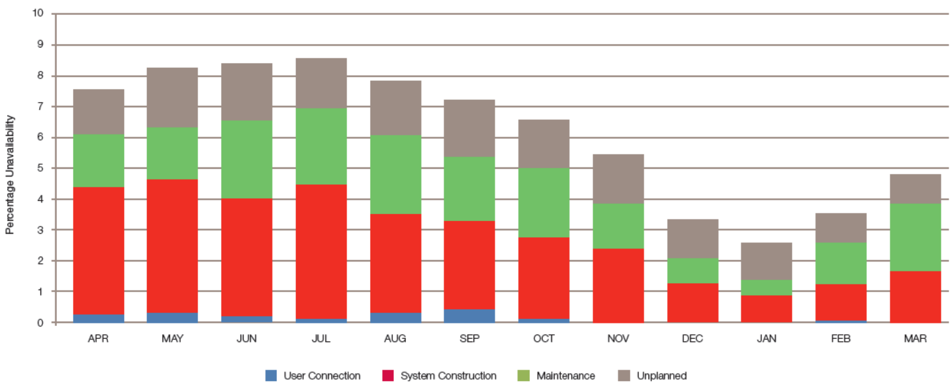


Figure 2. Monthly variation in Planned and Unplanned System Unavailability for England and Wales Network

System Unavailability is calculated by the formula:

System Unavailability = (100 - Availability) %

Unavailability falls into 4 categories, 3 of which are planned and the other unplanned Figure 2:

- Maintenance Outages are planned outages required for maintenance;
- System Construction Outages are planned outages required to construct or modify assets which are not provided for the exclusive benefit of specific users;
- User Connection Outages are planned outages required to construct or modify assets which are provided to facilitate connection for the exclusive benefit of specific system users;
- Unplanned Unavailability is due to outages occurring as a result of plant or equipment failure, ie outages required and taken at less than 24 hours' notice.

Offshore System Availability is calculated using the formula

$$Offshore\ System\ Availab. = \frac{Total\ MWh\ system\ is\ capable\ of\ delivering\ -\ MWh\ unavailable}{Total\ MWH\ system\ is\ capable\ of\ delivering} \times 100\%$$

The Overall Reliability of Supply for a transmission system is calculated using the formula:

$$Reliability\ of\ Supply = (1 - \frac{Estimated\ Unsupplied\ Energy}{Tot.energy\ that\ would\ have\ been\ supplied\ by\ the\ transm.system}) \times 100\%$$

In Ireland, EirGrid and SONI publish the Transmission System Performance Report annually, referring to the system data of the previous year (Eirgrid, SONI, 2012). The yearly report includes grid development and maintenance tasks, transmission and generation system performance statistics, system minutes lost, frequency deviations and zone clearance rate. There are several more detailed analyses, including careful insight on the causes of outages and categorization, monthly availability, major events and energy lost. The approach for failures, outages and system availability is the same as in the NGET report. Additionally, they promote the system minute index as an indication of outage severity. *A system minute* is defined as the energy in megawatt-minutes not supplied from the system to consumers divided by the system maximum demand in megawatts for the year in question. When this index is greater than one minute the incident is classified as "major".

$$System\ minutes = \frac{energy\ not\ supplied\ by\ the\ event\ (MWh)}{System\ peak\ (MW)} \times 60\ (mins)$$

In France, RTE issues annual reports for the quality of electricity supplied by its network, presenting data for electricity outages, the energy not supplied and the excursions of system frequency and voltage (RTE - Reseau de Transport Electricite, 2015). *Equivalent outage time* (temps de coupure équivalent -TCE) is an indicator used to measure the quality of the electricity supplied by RTE. It is calculated as a ratio between:

- *Total energy not served* during times when no power is delivered to RTE's distributor and industrial customer sites (excluding the energy and rail sectors);
- *The average power served* annually by RTE to these same customers.

During 2014, the equivalent outage time for RTE customers was 2 min 46 sec, excluding exceptional events. This result reflects the actions RTE has undertaken to improve the quality of the electricity supplied to its customers. Since there is a target value in the French regulation by CRE (French regulatory authority), further actions must be taken to move within the 2 min 24 sec limit set out in the incentive regulation.

Since 2013, outage frequency has been factored into the French incentive regulation created by CRE to encourage continuity of supply. It corresponds to the *average number of short outages* (between 1 sec and 3 min) and *long outages* (more than 3 min) experienced during the year by RTE's distributor and industrial customers (excluding the energy and rail sectors). During 2014, outage frequency excluding exceptional events was 0.46, which was lower than in 2013. This result was well within the 0.6 limit set out in the incentive regulation, and was even below the average of the past ten years (0.54)**¡Error! No se encuentra el origen de la referencia.**.

In Spain, the Spanish TSO REE publishes yearly a report on the Spanish electricity system which provides information on several issues such as: electricity demand, demand coverage, generation system details, system and market operation data, transmission infrastructure works, service quality, international exchanges and comparison details. The performance monitoring results are presented in the section "service quality" where a variety of indices are presented such as: energy not supplied (ENS) due to incidences in the transmission grid, average interruption time (AIT) due to incidences in the transmission grid, annual evolution of the grid availability (REE, 2012). The data presented in 2013 are illustrated in Table 1.

	2009	2010	2011	2012	2013
Grid availability (%)	98.04	97.93	97.72	97.78	98.13
Energy Not Supplied (ENS) (MWh)	437	1,552	259	113	1,126
Average Interruption Time (AIT) (minutes)	0.910	3.135	0.535	0.238	2.404

Table 1. Reliability indices of Spanish system

IEEE has issued standard 1366 regarding reliability indices for electric utilities and many countries follow this as a template to monitor their network performance (IEEE Standard, 2012). In the USA, most utilities follow IEEE standard. The basic set of indices and definitions they use are presented in the following Table *2*. Among the utilities that provide these annual reliability reports are Pacific Power, Liberty Utilities, San Diego Gas&Electric (SDG&E), Pacific Gas and Electric (PG&E) (Pacific Power, PacifiCorp's, 2014), (Liberty Utilities (Calpeco Electric) LLC), (San Diego Gas & Electric), (Pacific Gas & Electric (PG&E) Company). In Figure 3, the reliability indices for California published by Pacific power in (Pacific Power, PacifiCorp's, 2014) are illustrated.

INDEX	DEFINITION
SAIDI	**System Average Interruption Duration Index**, represents the sum of customer-sustained outage minutes per year divided by the total customers served.
SAIFI	**System Average Interruption Duration Index**, represents the sum of customer-sustained outage minutes per year divided by the total customers served.
CAIDI	**Customer Average Interruption Duration Index**, for the group of customers that actually had one or more interruptions and how long (on average) the interruptions lasted. The figure represents the total number of customer interruption durations divided by the total number of customers interrupted.
AENS	**Average Energy Not Supplied Per Customer Served** (kWh/year, customer). The index represents the total energy not supplied divided by the total number of customers served.
CEMI-X	**Customers Experiencing Multiple Interruptions**, a measure of the percentage of customers who experienced X interruptions. CEMI-3 is the percentage of customers who had three or more interruptions.
CELID-X	**Customers Experiencing Longest Interruption Durations**. CELID-8 is the percentage of customers who experienced outages exceeding 8 hours.
MAIFI	**Momentary Average Interruption Frequency Index**, represents the system-wide average number of momentary outages per year and is the number of momentary customer interruptions divided by the total customers served. A momentary interruption is typically defined as any interruption that is less than the definition of a sustained outage.
CEMMI-X	**Customers Experiencing Multiple Momentary Interruptions** is a measure of the percentage of customers who experience X momentary interruptions.

Table 2. Reliability indices for electric utilities

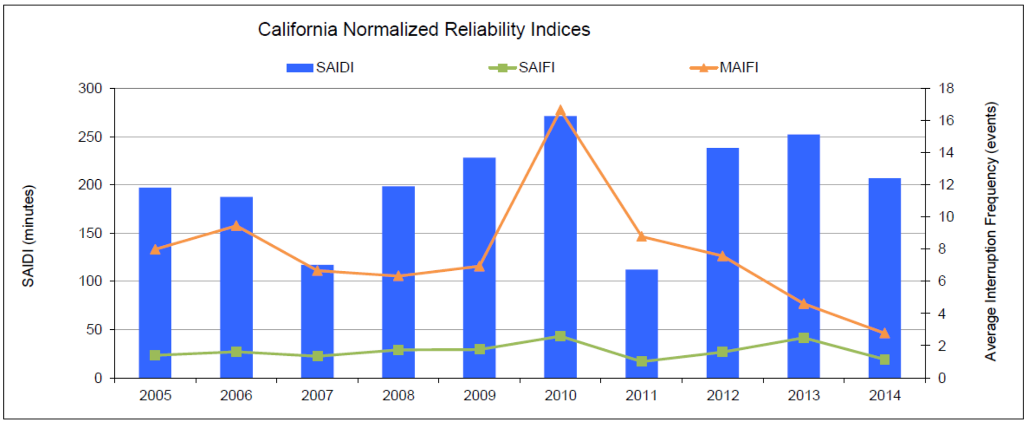


Figure 3. Reliability indices published in (Pacific Power, PacifiCorp's, 2014).

In Australia, all transmission network service providers monitor their performance with a wide variety of indices similar to the above mentioned, grouping the data in respect with the area or the time period to provide more detailed indices. The calculated values are compared with upper ('cap') and lower ('collar') acceptable values in order to provide incentive to the service providers for high reliability. In the case of high or low performance, a financial reward or penalty is calculated in the regulated revenue of the provider, based on the S-factor (service standards factor) metric and the respective mathematical formulation. The detailed procedure is presented in (Australian Energy Regulator (AER), 2007).

3.2 Telecommunications sector

Society is increasingly dependent on the proper functioning of the telecommunications sector. It has a major impact on economy: increasing productivity; allowing the creation or relocation of enterprises to locations with better telco access and higher quality of life; creation of new employment as a result of relocation of companies or self-employment resulting from availability of communication networks; economic growth due to the increase in efficiency or consumer surplus generated by the availability of new telco services or reduction of travel time (Katz, 2009), (Hämmerli, Svendsen, & Lopez, 2012) [3]. Apart from the information-based economy,

[3] Also: http://ec.europa.eu/growth/sectors/digital-economy/importance/index_en.htm

telecommunications networks are also important to health and public safety: e.g. the ability to make an emergency call to 112, or allowing the exchange of information among hospitals.

In addition, telecommunications is one of the most complex of the lifeline utility sectors: network complexity itself, rapid improvement of technology, change of providers and customer preferences, or inter-connectedness among the various providers to name a few (Auckland Civil Defense; Auckland Council, 2011).

That is the reason why different governments have regulations regarding the functioning of telco networks, and the accountability of their incidents.

3.2.1 Governmental Regulations

The directive 2009/140/EC of the European Parliament on a common regulatory framework for electronic communications networks and services, on access to and interconnection of electronic communications networks and associated facilities, and on the authorisation of electronic communications networks and services (European Commission, 2009) establishes, on Article 13a, the obligation of the National Regulatory Agencies (NRA) to inform the NRAs in other Member States and the European Network and Information Security Agency (ENISA) of any breach of security or loss of integrity (outages) that have had a significant impact on the operation of networks or services.

Electronic communication services included are:

- Fixed telephony (e.g. PSTN, VoIP over DSL, Cable, Fibre, etc.),
- Mobile telephony (e.g. GSM, UMTS, LTE, etc.),
- Fixed Internet access (e.g. over DSL, Fibre, Cable, etc.),
- Mobile Internet access (e.g. GPRS/EDGE, UMTS, LTE, etc.)

Incidents affecting other types of services, like TV broadcast, SMS or e-mail, for instance, may also be reported by NRAs. However, these reports are not mandatory.

Incidents reported that exceed a threshold are summarised annually in the ENISA “Annual Incident Reports”[4]. This threshold is defined on a “per service” basis and depends on the percentage of users affected within a Member State and the duration of the incident. Table 3 summarizes the

[4] https://www.enisa.europa.eu/activities/Resilience-and-CIIP/Incidents-reporting/annual-reports

circumstances or impacts in which incidents shall be reported (in red). In the other cases (green), NRAs have the discretion to report incidents.

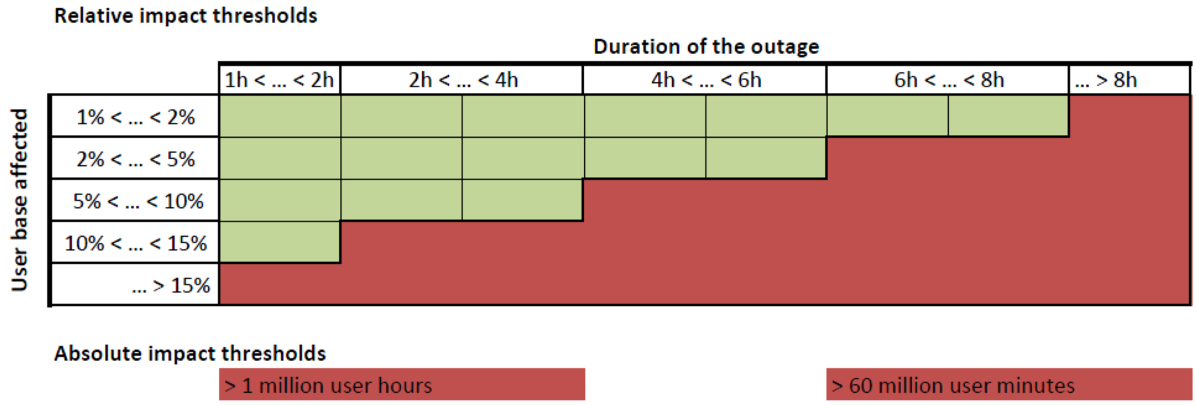


Table 3. Threshold for annual summary reporting based on a combination of duration and the percentage of the Member State user base. Adapted from *(Dekker, Karsberg, & Lakka, 2015)*.

In 2014, thresholds based on absolute impact were introduced that consider the product of number of user connections and duration of the outage. Thus, since 2014 it is also mandatory to report incidents that affect more than 60 million user minutes, or 1 million user hours.

Root causes of incidents are categorized in four groups: natural phenomena, human errors, malicious attacks, and system failures. In the scope of RAIN project, the attention is focused on the first category. According to ENISA, natural phenomena category includes incidents caused by severe weather, earthquakes, floods, pandemic diseases, wildfires, wildlife, etc.

Annual Incident Reports 2014 - Analysis of Article 13a annual incident reports (Dekker, Karsberg, & Lakka, 2015) shows that natural phenomena are responsible for only 5 % of the incidents on premises reported by all 28 EU Member States and 1 EFTA country. 9 % of incidents related to third parties failures (16 % of total number of incidents) are due to natural phenomena. Third parties failures include, for instance, power outages. Then, about a 6 % of the (large[5]) incidents related to electronic communications occurred in Europe during 2014 were caused by natural phenomena. However, failure recovery times are the largest for those caused by natural phenomena. On average, 81 hours are required to recover from the outage.

[5]It is important to remind that this report is skewed towards large incidents, those that exceed the thresholds. In 2014, 137 reports about major outages/disruptions impacting electronic communications services were registered.

Looking at the specific cause of the incidents related to natural phenomena, 33 % are associated to heavy snow/ice, 33 % to fire, 17 % to heavy wind, and 17 % to flood. Within this group, the largest average numbers of user connections affected per incident are when there is heavy wind or heavy snow/ice. The longest average recovery time corresponds to heavy snow/ice (100 hours), followed by heavy wind (72), and fire (61).

Two anonymized examples presented in the same annual report are related to extreme weather conditions:

1) Ice storm caused outages in all services for up to two weeks affecting thousands of connections (including all services) and even the emergency call service were interrupted. The main cause for the loss of services was the interruption of power supply (heavy ice on cables destroyed a large number of power lines and pillars);

2) Heavy snow interrupted power supply causing mobile networks to fail during several days, affecting thousands of connections. In addition, road accesses to facilities were closed (also due to the extreme weather event), thus difficulting the remediation of the problems. These two cases exemplify how power and telecommunication networks are intimately related, and also the important role played by road access and transportation (discussed in Deliverable D3.1) to E & TC facilities.

Governmental *incident* definitions may differ between countries. In the **United States of America**, for instance, each state has its own definition:

- In Texas, each Local Exchange Carrier (LEC) is required to notify the Commission when a service interruption has occurred for four hours or more affecting 50% of the toll circuits serving an exchange, 50% of the extended area service circuits serving an exchange, 50% of a central office, and 20% or more of an exchange's access lines; or any component of the 911 system6 that results in an outage to the 911 service (Public Utility Comission of Texas)].
- The state of New York defines major service outage as any of the following cases: a service problem or newsworthy event at a service provider's building(s), or other event, caused by, extreme weather events, fire, job action, sabotage, civil unrest, death, a cyber or physical security breach for instance; a service problem affecting public access to 911, operator services, Telephone Relay Service, police, fire departments, or emergency medical services; a service problem that disrupts the delivery of Emergency Alert System (EAS) provided emergency information to the public; a major network node and/or telecommunications traffic concentration point failure lasting more than five minutes; extensive network

[6] USA equivalent to Europe's 112 emergency call system.

congestion or call blockage; any failure affecting 100 or more subscribers; a service problem affecting a public transportation terminal, hospital, national defence installation, large residential and commercial building or complex, or other major customer, such as a utility or other Telecom service provider (New York State Public Service Commission).

An example of a telco failure related to extreme weather happened in New York City in 2012, due to the hit of hurricane Sandy. Telecommunication network failures that day were caused by power outages (due to direct effects of the storm, or preemptive actions taken to minimize the impact of the potential downtime of the electric system), and flood. The largest number of customers affected came from utility power outages (those affected over 2 million New Yorkers). However, the longest recovery time (up to more than 100 days) was caused by flood damage at telco infrastructures or at customer buildings (35.800 buildings are estimated to have experienced flooding that likely affected telecommunications equipment). (City of New York, 2013).

Network outages in **Lebanon** (Republic of Lebanon) are classified in four groups:

- outages affecting emergency services
- critical, outages affecting the entire network, the core of the network or greater or equal to 30 % of the traffic;
- major, affecting a part of the network, and influencing less than 30 % of the traffic;
- minor, affecting individual sites, and/or components that do not interrupt service or performance; and

In most cases, local, regional, or state governments investigate and prepare reports on important outages to minimize future impact of similar failures, by proposing preemptive and mitigation measures. For instance, the European *Annual Incident Reports* (Dekker, Karsberg, & Lakka, 2015), the New York City's *A stronger, more resilient New York* report on effects of Sandy hurricane (City of New York, 2013), or the extensive report prepared by the Australian Government after the Warrnambool exchange fire, *Inquiry to learn lessons from the Warrnambool exchange: Report* (Gregory & Scholfield, 2014) & (Australian Government, 2013)

4 Social Effects

This section provides a summary of the various socioeconomic effects of electrical or telecommunication networks failures qualitatively. In the following section, different assessment methods are presented. Actual values from case examples are shown in the Examples section.

Telecommunication networks have an important socioeconomic impact at a number of levels from labour productivity (greater efficiency in processing of information-related tasks), to innovation capacity (streamlined collaboration among ecosystem firms is facilitated) (Katz, 2009). Thus, a failure in telco infrastructure strongly affects productivity of the country/region and also the welfare of their citizens.

Regarding power networks, indirect effects may be as important as direct effects. The latter include interruption of service originated at the production, transmission, or distribution systems with the consequent loss of power access by the customers (housing and business or industry). Among the indirect impacts, one can distinguish, for instance: several third parties that need continuous power supply for proper operation, e.g. telecommunication operators; other utility providers (water supply, natural gas); sewage systems; public transportation, mainly train and underground railway system, air traffic (Crane, 1990)& (Hämmerli, Svendsen, & Lopez, 2012).

The impact of failure events in electrical and telecommunication infrastructures can be divided at different levels. One may distinguish *physical* impacts, e.g. disruption of public transportation; from *socioeconomic* impacts, that can include social, psychosocial, demographic, economic, and political impacts, e.g. the inability to arrive at your working place due to the disruption of public transportation (Lindell & Prater, 2003) & (Hasan & Foliente, 2015). The impact of outages can be classified also in terms of direct economic impacts, indirect economic impacts, and social impacts (Linares & Rey, 2013). The effect of a failure in electrical or telecom service can also be divided regarding the group of users affected, as done in the following.

Figure 4. Luggage belonging to passengers piles up following a power outage at the North Terminal of London. Gatwick Airport in Horley, England, Tuesday Dec. 24, 2013. (Photo: Sang Tan , AP)

Figure 4 shows the impact of an outage in an airport, caused by a storm. (USA TODAY - Winter storm blasts Europe, wreaks travel chaos).

Groups of **users** of electric and telco networks can be divided into three main groups: business (industrial, commercial, and agricultural firms), public/community service providers, and individuals/residential (Gregory & Scholfield, 2014), (Australian Government, 2013) & (Crane, 1990). Then, social impact and consequences of failures in E & TC networks can be split in these groups, as summarized in *Table 4*.

Some **consequences** are shared by all three groups: food spoilage, damage to electronic devices, loss of goods, or public transportation issues, for instance, are possible impacts with vast influence in the case of a power outage. Looting and vandalism may be also considered as indirect effects in case of a prolonged blackout.

Looking at the effects group by group, one of the most important general impacts of a failure in the telecommunications network at the **business** side are the difficulties in financial transactions: online banking access, or credit card payments are compromised, and also interaction with local bank branches, which rely on telecommunication services to work properly. Specific impacts in business include reduction of activity in stores, loss of access to information about a specific market (e.g. inability to contact brokers by agricultural producers) or booking systems (in tourism industry). Regarding power outages, shutdown and restart costs may have important impact in industry, together with the problems that affect other utilities derived from the power blackout (e.g. sewage system, or water distribution network).

As for the **community service providers**, i.e. healthcare system, council services, police and firefighters, the loss of telecommunications network has a repercussion at different levels. It can affect the access to emergency call-centres (European number 112), with all the risks associated, especially for vulnerable people (old people, children, and people with certain pathologies). It also affects the coordination among the different parties in order to mitigate the effect of the outage. Nevertheless, police, firefighters, and ambulance system usually have independent communication systems which are less vulnerable. Power network outages have major effects on life-support systems at either home or hospitals.

Regarding the impact on **individuals**' lives, the main social consequences of both telco and electrical outages are the increase of anxiety levels, and sense of isolation. In particular, elderly people living alone and people with health concerns are especially affected. One of the main complaints is the loss of leisure time. In socioeconomic terms, individuals also suffer the consequences of the loss of access to financial transactions in the case of a telco failure, and difficulty to work either due to the reduction in business activity, or because they telework.

In all cases, apart from the impact on the different types of clients, these effects will have different repercussion depending on a number of other parameters (Walker, Cox, Loughhead, & Roberts, 2014), (Grünewald & Torriti, 2012): perceived reliability level (that may determine the investment or not in backup system), moment (e.g. time of the day, season of the year), geographical area, socioeconomic characteristics of the affected area, outage duration, frequency of outages, structural vs. incidental interruption or notified vs. not-notified (that may allow customers to prepare), the source of the outage (may strongly influence on the price of the energy, thus having an important impact on users wealthiness).

Social Effects due to Electrical [E] or Telco [TC] failures	
Business	● Financial transactions [TC] ● Opportunity costs of idle resources [E, TC] ● Shutdown and restart costs [E] ● Lost access to business-related information [TC] ● Public Transportation [E] ● Damage to electronic systems [E] ● Other utility providers (e.g. water) [E] ● Looting and vandalism [E] ● Loss of goods [E] ● Uncomfortable temperatures at work [E]
Community service providers	● Access to emergency call-centres [TC] ● Special attention to vulnerable people [E, TC] ● Coordination among different affected parties [TC] ● Public Transportation [E] ● Damage to electronic systems [E] ● Life-support systems [E] ● Other utility providers (e.g. water) [E] ● Looting and vandalism [E] ● Loss of goods [E] ● Uncomfortable/dangerous temperatures at work [E]

Individuals	● Increase of anxiety levels, sense of isolation [E, TC]
	● Special attention to
	    ○ elderly people [E, TC]
	    ○ people with health concerns [E, TC]
	● Work [E, TC]
	● Financial transactions [TC]
	● Public Transportation [E]
	● Damage to electronic systems [E]
	● Other utility providers (e.g. water) [E]
	● Looting and vandalism [E]
	● Loss of leisure time [E, TC]
	● Loss of goods [E]
	● Uncomfortable/dangerous temperatures at work/home [E]

Table 4. Based on *(Munasinghe & Sanghvi, 1998)*.

Industries and business functions that are severely hampered by power failures (Top 10 Industries that would be Affected Most by a Power Outage).

Classified by type of industry, the main effects of power outages are summarized:

- **Manufacturing Industries.** Power outages bring production lines to an abrupt halt. This may translate into
  - loss of material,
  - breakdown of machinery, and
  - loss of productive time.

  This may also cause supply chains to shut down altogether.

- **Financial Corporations.** It is not difficult to imagine the chaos a power outage can cause to the stock market. In an industry where millions of dollars can be made in profit within a fraction of a second, power outages render financial corporations unable to carry out crucial transactions on time. This is synonymous with millions of unrecoverable dollars per minute of downtime followed by several additional hours of recovery time.
- **Consulting and Information Technology (IT) Services**. Consulting services firms and software development facilities house hundreds of highly paid professionals. Even a brief period of downtime leaves them stranded and results in loss of billable hours. In an age where IT operations are an organization's window to the rest of the world, power outages result in
  - crashed computer systems,
  - lost data and abrupt termination of communications with clients,
  - programs and data may get corrupted resulting in software recovery operations that may not be resolved for weeks.

  This is often followed by several weeks of effort spent in recreating hundreds of man-hours of work.

- **Data Centers**. Data centers form the backbone of operations for several organizations such as financial services firms, insurance companies, and IT services firms among many others. Power failures here can cause an irrecoverable loss of thousands of records stored over the years and disrupt ongoing transactions as well.
- **Perishable Items**. Pharmaceutical industries, petrochemical industries and food processing plants rely heavily on uninterrupted availability of power for storage and preservation of perishables that have extremely limited life spans. Power outages can cause in-process products worth several millions of dollars to be discarded due to damage, spoilage or contamination.
- **Control Centers**. Traffic signal operations, public transport systems like the railways, control centers for air traffic management, telecommunications and utilities, all rely heavily on continuous power supply for smooth functioning. Disruption in such critical operations can jeopardize the safety and security of millions of unsuspecting consumers in an instant.

- **Medical Facilities**. In hospitals, patients' lives are delicately supported by health monitoring systems. Any discontinuity in the normal functioning of medical equipment can directly translate into loss of many lives.
- **Military Operations.** Power outages render valuable equipment, weaponry and even personnel, defenseless, and hence, exposing them to the risk of attack.
- **Entertainment Venues.** Cancellation of money-spinning events even for brief periods of time equates to huge losses of revenue for entertainment facilities. For instance, an extended power outage in a casino can translate into losses of more than US$ 1mn per day. In addition to resulting in forced losses of revenues, abrupt termination of routine operations can also become hazardous to visitors and operating personnel as well.
- **Safety and Security.** In addition to causing inconvenience, power outages can endanger the safety of the common man.

    - People trapped in or out of buildings with automated access control systems,
    - elevators that come to a sudden halt and are plunged into darkness,
    - fire alarms and water sprinklers that cease to function,
    - inability to communicate via phone or email with emergency services,

These are just a few examples of power outages becoming more than just a nuisance factor and threatening to endanger the safety and lives of millions of people simultaneously.

5 Measuring social impact

Assessment of the social impact of electricity or telecommunication networks (or any CI) due to an extreme (weather) event is not easy. There is not a clear (numerical) measurement that can be assessed in all cases, especially regarding soft measurements (Nooij, Private Communication, 2015). In addition, as mentioned in the previous section, a number of elements determine the aftermath of such events. For instance, the *impact ratio*, i.e. the amount of damage divided by the amount of community resources, is of vital importance in understanding disaster impacts (Lindell & Prater, 2003). Especially since it determines the available resources to mitigate the effects of the event: e.g. if only a small region of a country is affected by a blackout, technicians from other regions can be diverted to mitigate the problem, which would be impossible if the major part of the country was affected. It is important to remind that social impacts also strongly depend on the duration of the disruption of service. The European thresholds for incident report (Table 3) try to reflect both facts. However, these events may have long-term effects, which have difficult measure.

To assess electricity disruption costs, different approaches are used. These methods could be extended to analyse the effect of telco disruptions. Four of them are listed below, the first three methods being the most commonly used (Walker, Cox, Loughhead, & Roberts, 2014), (Linares & Rey, 2013), (Centolella, 2013) & (Grünewald & Torriti, 2012):

- **Customer surveys**. Their aim is to get the value of interruption costs from customers. Direct assessment is possible only in some cases (e.g. industrial sector). In the other cases (e.g. residential), indirect evaluation methods are utilized. Customers are asked their Willingness To Pay to avoid outages (WTP) or Willingness To Accept compensation for having a higher number of interruptions (WTA), the former measure being preferred when asking for the value of electricity supply security. However, this approach may provide biased results since the provision of security of supply is typically a public good and thus it can *suffer from free-riding effect*, i.e. *typically customers will have an incentive to give higher values to interruption costs* (Linares & Rey, 2013). This indirect method is also called **stated preference** approach.
- **Case studies**. Past events are analysed, then, estimations of costs are more detailed and based on actual outages. However, only limited and specific information is available (incidents occurred in particular circumstances).
- **Production function approach**. Using this method the goal is to get the Value of Lost Load (VoLL) by computing the ratio of an economic measure, like the gross domestic product, and a measure of electricity consumption, e.g. kWh. Then, it is usually given in terms of €/kWh. This approach assumes that electricity is a requirement for production and that the

production process cannot be shifted to other time slots, which may not be true in some cases. Therefore, VoLL may overestimate electricity disruption costs. On the other side, oftentimes using this method only production losses are considered, then other impacts such as equipment damage are not quantified. Finally, cost of **lost leisure time** can be also included. It can be monetized by using Becker's model (Becker, 1965) as de Nooij and coworkers propose (Nooij, Koopmans, & Bijvoet, 2007).

- **Market behaviour**. This approach is based on the expenditures on backup devices/facilities and the use of interruptible contracts[7]. These expenses can reflect how the WTP of the customers. It is also known as **revealed preferences**. However, in regions with high reliability networks (30 min of supply interruptions a year on average, or less) it is unlikely to invest in backup technology due to its cost-effectiveness. On the other hand, some community service providers (e.g. hospitals) must be equipped with backup systems. Therefore, these indicators cannot be used to estimate the costs of an outage.

5.1 Value of Lost Load

Value of Lost Load is *one of the most commonly-accepted means of assessing the economic costs of electricity supply interruptions*. It is defined as the ratio of an economic measure and a measure of electricity consumption. However VoLL is *not a value-neutral measure*, since it may depend on of people's perceptions of the value of a unit of electricity (Walker, Cox, Loughhead, & Roberts, 2014) (particularly when computed using WTA or WTP values instead of a specific economic measurement). Therefore, the considerable discrepancies that exist between cost estimates from different methods of calculation are justified.

VoLL also varies for different sectors (business, community services, individuals) and within them. In the business group, for instance, VoLL is relatively low in most cases but also a minority has extremely high VoLL. VoLL also depends on demand, that changes continuously. *Figure 5* shows the average demand as a function of the hour of the day for the three days with maximum consumption in 2010 in the UK. Peak state-wise demand is reached when non-residential customers are still consuming their *working hours* energy, but also residential energy use starts increasing. At those times, VoLL is also at its peak (Walker, Cox, Loughhead, & Roberts, 2014). Particular cases of VoLL assessed for different European countries are presented in Examples section below.

[7] Interruptible contracts allow for interruptions to electric service at certain times (e.g. during peak times between 4pm and 7pm) for reductions on their electricity bill.

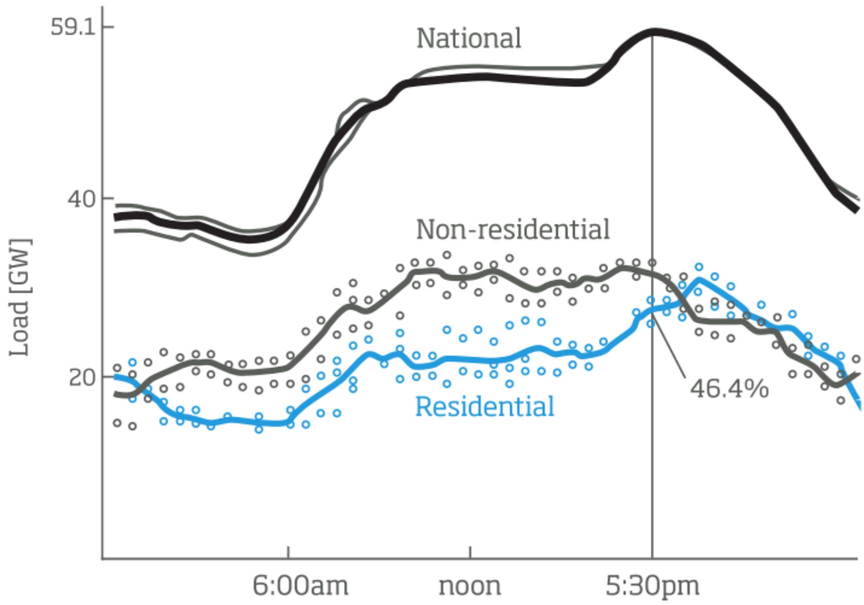


Figure 5. Average load values for three days with highest demand in 2010 in the UK as a function of hour of the day. Figure reproduced from *(Walker, Cox, Loughhead, & Roberts, 2014)*, data extracted from *(Grünewald & Torriti, 2012)*.

5.2 Social Impact Magnitude

A new method for explicit calculation of societal consequences of failures in critical infrastructures was recently proposed by Larsson et al. in “Assessment of Social Impact Costs and Social Impact Magnitude from Breakdowns in Critical Infrastructures” chapter in (Australian Government, 2013)[8]. Economic costs are measured in terms of the Gross Domestic Product (GDP), i.e. **production function approach**. As for non-economic consequences, in that work a new measure to assess them is also presented: **Social Impact Magnitude** (SIM), indicator that resembles Richter scale used to quantify the energy released by an earthquake.

To be able to analyse different kind of societies, Larsson and coworkers developed a *Virtual Society*, a model of Western society, that can be parameterized to represent many real countries (including European Union Member States, Norway, and Switzerland). In this Virtual Society power demand is

[8] specifically this chapter (Larsson, Björkman, & Ekstedt, 2013).

related to production and consumption of GDP. The dynamics of the society (e.g. daily, weekly, seasonal profiles) are considered to set individual Power Load Profiles or Business Activity Profiles for each element in the model (i.e. individuals or relevant objects in the city). The model is created and assessed by Virtual Cities Simulator (ViCiSi), a software package developed within the VIKING FP7 European Project (Vital Infrastructure, Networks, Information and Control Systems Management, 2008-2011).

In their model, outages are introduced as a total lost of production and consumption of welfare during the failure (a *reasonable simplification*, according to the authors). Power restoration and *economic restoration of the society* is more complex: due to the open and closed loop characteristics of the latter, normal operation regime requires longer to be reached. *Figure 6* exemplifies an outage episode and the subsequent normality restoration.

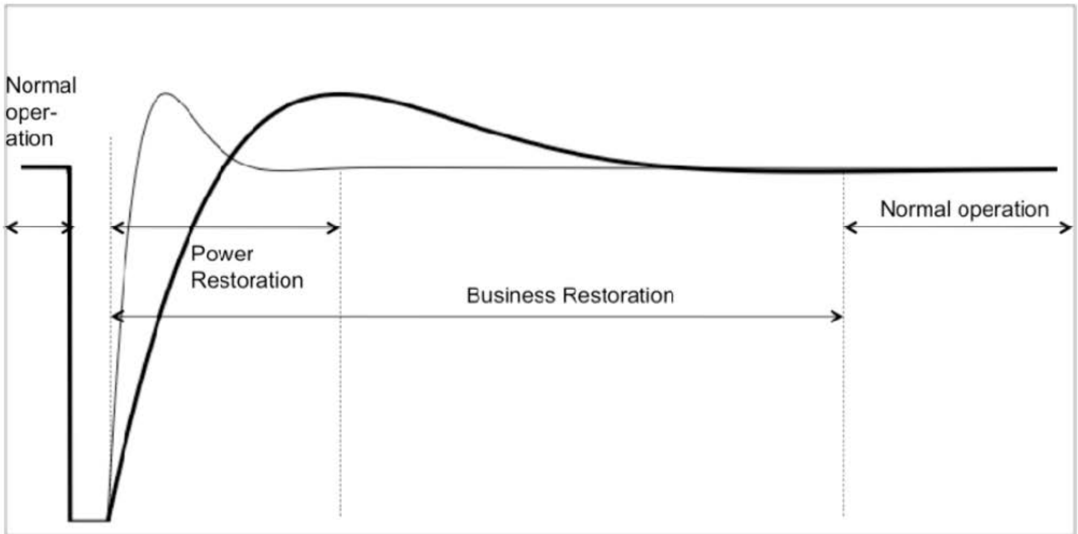


Figure 6. Restoration functions of power and business activity (thin and thick lines respectively) considered in *(Hämmerli, Svendsen, & Lopez, 2012)*. An outage occurs when both activities decrease after a normal operation regime.

The Social Impact Costs (SIC) assessment is calculated as the difference between normal, undisturbed operation GDP values and GDP during the outage and restoration, thus considering only economic costs. A supplementary non-economic approach is based on the **Social Impact Magnitude** (SIM). It divides the impact of an outage in two: at the micro scale, i.e. affecting individuals and their loss of welfare due to, for instance, problems with transportation or loss of leisure time; at the macro scale, that is from the society standpoint, where consequences are related to wider risks like disease proliferation or vandalism. At the micro scale, the important parameter is the **duration of the outage** (A_{length}) (in seconds), that defines the *Disturbance Length Order*; at the macro scale, the important factor is the *Impact Incidence*, i.e. the **number of affected people** (A_{people}) (divided by 1000) (Hämmerli, Svendsen, & Lopez, 2012). Then, social Impact Magnitude is defined:

$$SMI = Impact\ Incidence + Disturbance\ Length\ Order,$$

$Impact\ Incidence = \text{Log}_{10}(A_{people})$, and $Disturbance\ Length\ Order = \text{Log}_{10}(A_{length})$.

Therefore, SMI is obtained as:

$$SMI = \text{Log}_{10}(A_{people} \cdot A_{length})$$

According to the authors, SMI impact can be summarized as shown in the following table:

0 ≤ SMI < 3	None or small problems
3≤ SMI < 5	Problematic
5≤ SMI < 7	Severe problems
7≤ SMI	Critical problems

Table 5 Social Impact Magnitude scale, adapted from (Hämmerli, Svendsen, & Lopez, 2012)

This indicator can be related to EU thresholds for annual summary reporting based on absolute impact: one million people hour or 60 million people minute corresponds to SMI = 6.55, i.e. severe problems. However, if thresholds relative to the population of the Member States are considered, a *relative SMI* (rSMI) should be defined. For instance, rSMI could be defined the same way as SMI, but changing the number of affected people (A_{people}) by the percentage of affected people per Member State user base$(A_{r\ people})$. In this case, threshold value could be set at $rSMI \geq 4.6$ (to be in reasonable agreement with the actual European values shown in Table 3.

Another possibility would be to define a Mercalli intensity- or Shindo- equivalent scale for social impact evaluation of electrical and telecommunication networks outages. However, those scales only focus on the final or total effects of an earthquake, while in the case of outages it is also important to consider and include the temporal dimension.

5.3 Other measurements

Hasan and Foliente review the current literature in relation to modeling infrastructure interdependencies and the socioeconomic impacts of failure in extreme events (Hasan & Foliente, 2015). Given the importance of the interdependencies among infrastructures (e.g. power access is needed for telco networks to work, or gas distribution may be required for the power grid to properly operate), different approaches to assess the interdependencies are listed in that paper. In this deliverable, however, the focus is on measuring the socioeconomic impacts of outages.

As for the economic effects, modeling approaches, based on economic theories, are categorized in two: Input-Output (I-O) models and Computable General Equilibrium (CGE) models. The former models are widely used to assess impacts, especially at the regional scale. However, one of the main disadvantages of these models is their linearity. This deficiency of the I-O models is overcome by CGE models that allow capturing non-linear interactions and enable to consider different types of interdependencies in a single framework, thus these models have gained popularity .

The social impact of disruptions is not usually explicitly assessed, primarily because of the intrinsic difficulty in quantifying social effects. However, a number of studies attempt measuring social impacts of lifeline losses in earthquakes and other natural disasters (Chang, Pasion, Yavari, & Elwood, 2009), focusing on the number of displaced people and the reduction in operability of healthcare facilities; or the effect of floods, also highlighting the shelter needs in the aftermath of the extreme event (Scawthorn, et al., 2006). A wider-scope analysis, in terms of assessing community impacts of natural disasters, is found in (Lindell & Prater, 2003). The authors emphasize the complexity of measuring those effects since the hazard mitigation and emergency preparedness practices (at the *physical* level), as well as the community recovery resources or the extra-community assistance (at the *socioeconomic* level) extremely influence the consequences of an outage.

5.4 Dedicated software

5.4.1 Hazus-MH

A nation-wide operating software that uses a standardized methodology that contains models for estimating potential losses from earthquakes, hurricane winds, and floods is **Hazus-MH** (Multi-Hazard) (Federal Emergency Management Agency of USA). This software was developed by and is improved by the Federal Emergency Management Agency (FEMA) of the USA. Hazus-MH uses

Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters before they happen. To estimate these quantities it also implements physical models to simulate these extreme conditions. An example of simulated possibilities of flood is shown in *Figure 7*. Direct utilization of this software in other countries is difficult due to the lack of tools to integrate non-US data sets in its framework. However, attempts to implement a new toolset that allows Hazus-MH to be used to estimate losses in other countries have been performed (i.e. HAZ-I toolset). Even though HAZ-I toolset provides a promising perspective to apply Hazus-MH worldwide, further research is still needed.

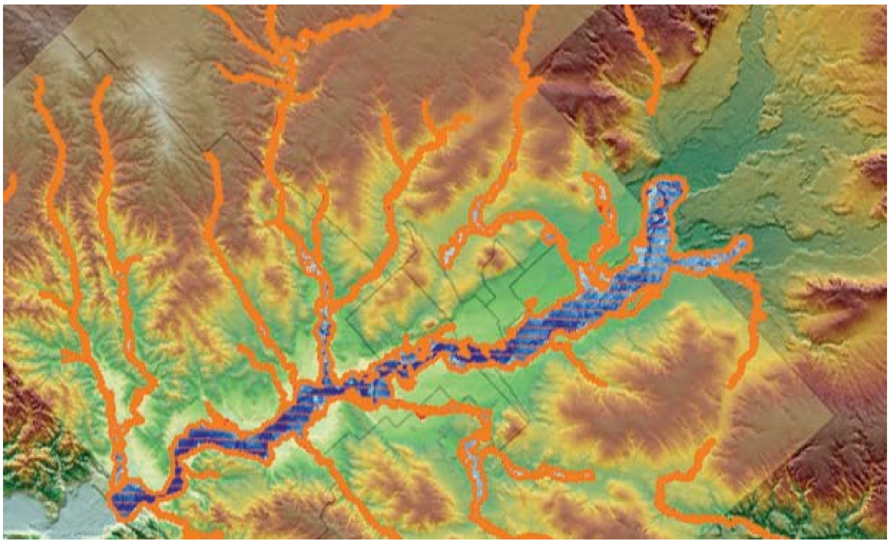


Figure 7. Example of Hazus-MH *(Federal Emergency Management Agency of USA)* simulation of flood risk.

5.4.2 Blackout simulator

The **Blackout simulator** (Energie Institut; Johannes Kepler Universität Linz; Sesame Project)& (Reichl & Schmidthaler, 2014) was developed within the SESAME FP7-security project co-funded by the European Commission (Sesame Project). The aim of this software program is to assess the amount of electricity not provided within an European region (or a number of them) at a given day and during a certain amount of time due to a complete blackout. It also calculates the economic damages as consequence of this power outage. Energy not supplied and costs are assessed per economic sector activity grouped by NACE-code[9]. The simulator uses a combination of *soft data*

[9] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)

from surveys (from a large number of households being asked for the WTP) and *hard data* from official statistics, i.e. it uses the production function approach for firms and public sector, and the customer surveys approach for households. Since it is using the production approach, it assumes that all firm and public sector are productive and that all electricity is a requirement for production (i.e. production stops completely during an outage).

Although Blackout Simulator only considers complete regional blackouts, it can be also used as a first approximation of the (economical) impact of an outage due to extreme weather events.

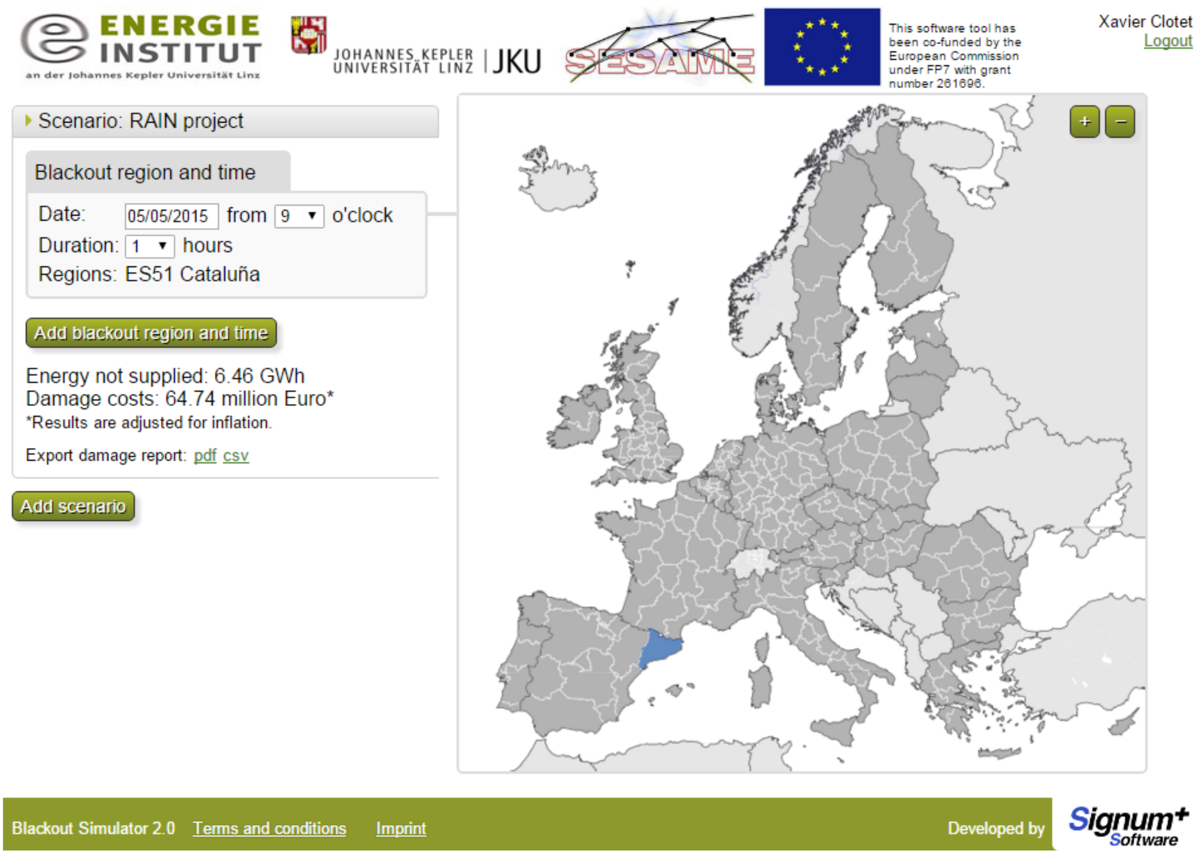


Figure 8. Screenshot of the Blackout Simulator 2.0 [*(Energie Institut; Johannes Kepler Universität Linz; Sesame Project)* & *(Reichl & Schmidthaler, 2014)* developed within SESAME EU project *(Sesame Project)*. Amount of energy not supplied and correspondent damage costs are simulated.

6 Examples

Economical and social impacts of case studies *Windstorms Lothar & Martin (France, 26-28 Dec. 1999)* and *Gudrun/Erwin windstorm (Sweden, 8 Feb. 2005)* presented in deliverable D4.1 of RAIN project are assessed using the methodologies described in section Measuring social impact of the present document, when data are available.

Recent studies analysing the cost of electrical failures in three European countries (Spain, The Netherlands, and the UK) are also described. In addition, data of Values of Lost Load obtained with a production function approach for Spain, The Netherlands, and Ireland are summarized in Figure 10. For the UK, VoLL estimated from the Blackout simulator (Energie Institut; Johannes Kepler Universität Linz; Sesame Project)& (Reichl & Schmidthaler, 2014) and from surveys (both WTA and WTB) are compiled in Figure 11 and Figure 12.

Finally, an example of the effects of an extreme weather event on the IT sector is presented.

6.1 Windstorms Lothar & Martin

As described in detail in D4.1, extra-tropical cyclones Lothar and Martin affected Western Europe on December 26-28, 1999. In particular, Lothar storm hit the northern part of France during the night of December 25 to 26; while Martin storm hit on December 27 around 5 pm (Eurelectric, 2006).

About 400000 costumers lost their electric connections due to the first storm. In terms of the Social Impact Magnitude (SIM) described in section 5.2, after the first 24 hours of the arrival of the storm, **SIM = 7.5** was reached (corresponding to critical problems). The hit of the second storm increased the number of affected users up to 3.4M people. That means a **SIM = 7.1** one hour after the hit and reaching a **SMI = 8.3** the following day (December 28) in the morning. Both cases corresponding also to critical problems as defined in Table 5.

In spite of the immediate efforts in repairing the damages caused on the grid, more than 100000 users were still affected 10 days after the second storm hit. That corresponds to **SIM = 8**. This high value of SIM is due to the extremely long duration of the outage for a considerable amount of people. Finally, the last users without service recovered power 15 days after the disruption. The Social Impact Magnitude here was still between 3 and 5 (problematic).

As for the economic losses, the total power not supplied was 0.7TWh. An estimation of costs made after the storm considered the costs of emergency repair, loss of sales, compensation (by the distributor), and investments in rebuilding totaling 1408M€. Therefore, an estimation of the Value of Lost Load of two storms would be **VoLL = 2 €/kWh**. However, this is probably an underestimation since not actual values of the GDP *lost* are considered.

6.2 Gudrun/Erwin windstorm

Gudrun (in Norway and Sweden) or Erwin (in Germany) windstorm hit southern Sweden on January 8, 2005. It had a major effect: for instance roads and railways in large areas of the south of Sweden were obstructed by fallen trees. Telco and electric connections were also strongly affected (Eurelectric, 2006).

Focusing on the impact on the number of costumers that lost connection, during the first day, more than 350000 people were affected (**SIM** about **7.4**). Almost 160000 people did recover the power during the following 3 days after the outage (**SIM ≈ 7.5**). During the first week more than 80000 people still had not connection to the electrical grid (**SIM ≈ 7.6**). More than 55000 people were still affected between 8 and 20 days after the incident (**SIM ≈ 7.9**). Finally, 12000 people had the service interrupted for more than 20 days (**SIM ≈ 7.1** assessed on the 20th day).

In this case it can be seen that SIM is a good indicator of the social impact of an outage: while the total number of clients affected diminished substantially (from 350000 people the first day to 12000 after 20 days) the Social Impact Magnitude stayed above 7. That is, it stayed in the *critical problems* impact level (as it was the actual case). The evolution of the affected people and SIM values as a function of time are shown in Figure 9.

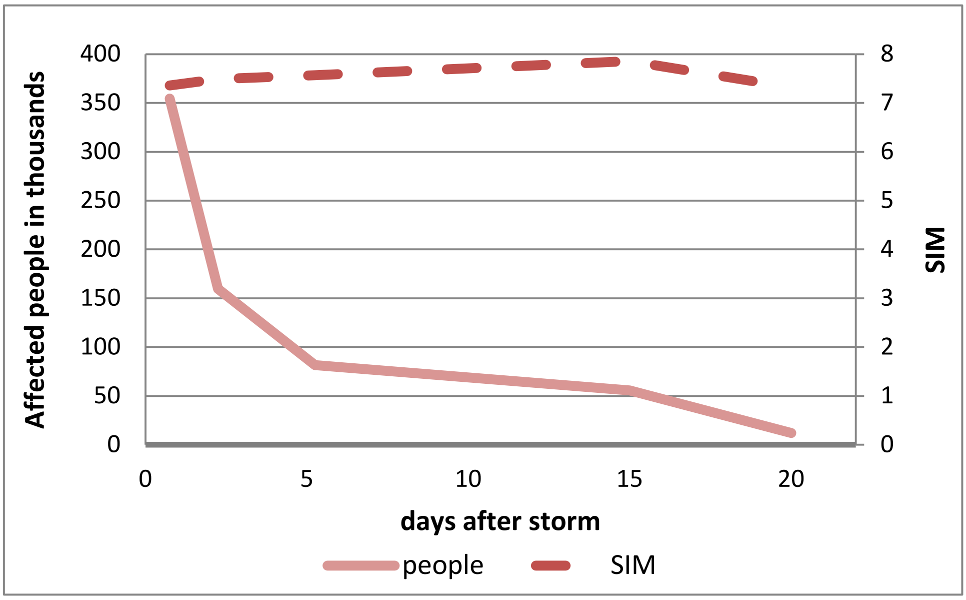
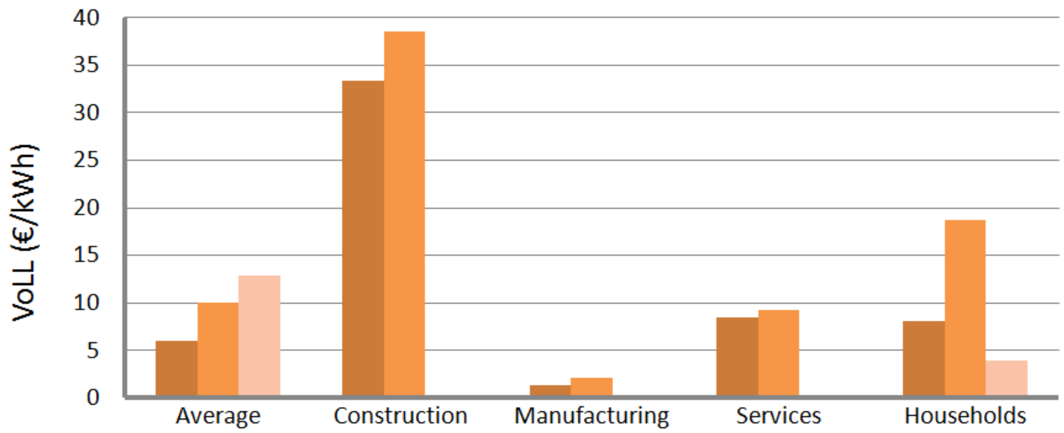


Figure 9 Number of affected people and Social Impact Magnitude after Gudrum/Erwin windstorm.

6.3 Spain

Linares and Rey analysed the costs of electricity interruptions for different sectors and regions of Spain (Linares & Rey, 2013). In particular the authors focus on the physical availability of power as a consequence of disruptions caused by generation and management decisions. The authors show how including or not including sectors in which electricity is not essential influences the final value of interruption costs. Leisure time is also monetized: in (Linares & Rey, 2013) the value of one hour of leisure time is assumed to be equal to the income per hour; i.e., the net hourly wage. The authors also consider that the *opportunity cost of leisure for inactive and unemployed people is lower*, estimating one hour of leisure time is equal to half of the average wage (following Becker's model (Becker, 1965), approach used for instance in (Nooij, Lieshout, & Koopmans, 2009)).

Considering all economic sectors, as of 2008 Spain generated 5,98 €/kWh on average. The highest VoLL was 33,37 €/kWh for construction, while manufacturing had the lowest VoLL (1,5 €/kWh). Households, services and transport VoLL are very similar, around 8 €/kWh. When only sectors in which electricity is essential (e.g. construction) are considered, the average VoLL increases up to 6,35 €/kWh. Linares and Rey also highlight the dependence of the Value of Lost Load on the hour of the day, specially for services and households (almost no variation for the industrial sector). It is also important to mention the variability as a function of the region considered: the highest economic cost of an outage in a region is three times higher than the lowest VoLL.



	Average	Construction	Manufacturing	Services	Households
Spain	5.98	33.37	1.38	8.47	8.11
The Netherlands	10.00	38.56	2.19	9.28	18.70
Ireland	12.9				4

Figure 10. Value of Lost Load for three European countries (in 2008 €). Data from (Linares & Rey, 2013), (Nooij, Lieshout, & Koopmans, 2009) & (Nooij, Koopmans, & Bijvoet, 2007).

6.4 The Netherlands

De Nooij and coworkers studied the value of supply security and the costs of power interruptions focusing their attention in the Netherlands (Nooij, Koopmans, & Bijvoet, 2007) & (Nooij, Lieshout, & Koopmans, 2009). The costs of outages are estimated in terms of lost production and lost leisure time. Average VoLL in the Netherlands in 2001 was 8,56 €/kWh. Again, big differences are observed by sector: construction sector 33 €/kWh, while manufacturing 1,87 €/kWh. As for the households, 16 €/kWh. The authors also comment on the variability of the VoLL per time slot of the weekdays, Saturdays, or Sundays. Regional changes in the Value of Lost Load are also observed: high VoLL in the areas around the largest lake in The Netherlands (IJsselmeer) caused by a high share of services, agriculture, and households in these areas, that implies a low proportion of manufacturing (lowest contribution to VoLL). The lost leisure or welfare losses of households are as important as the value added lost in firms, particularly in the evenings.

6.5 The UK

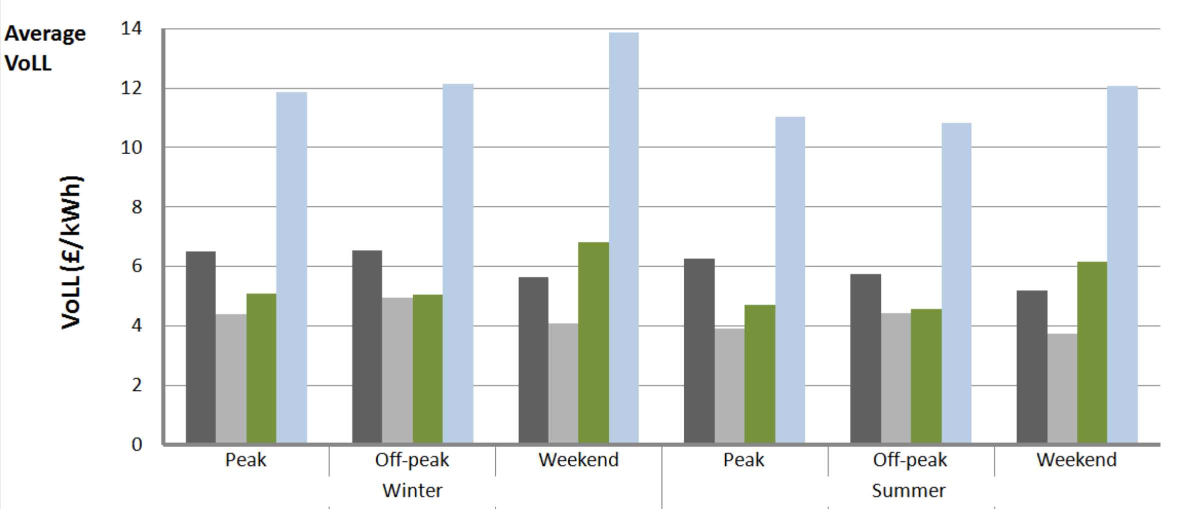
A report for the Council for Science and Technology of the UK written by the Royal Academy of Engineering analyses the cost of electricity shortfalls in the UK (Walker, Cox, Loughhead, & Roberts, 2014). Value of Lost Load is estimated using two methods: the blackout simulator (Energie Institut; Johannes Kepler Universität Linz; Sesame Project) & (Reichl & Schmidthaler, 2014) and via surveys to obtain the Willingness to Pay (WTP) and Willingness to Accept (WTA)[10] in the case of an outage.

As for the blackout simulator, the average VoLL for the UK is obtained for interruptions of one or 12 hour duration. Different scenarios are considered: winter/summer; and peak, off-peak, or weekend[11]. The same scenarios are studied by performing experiments conducting surveys to finally assess the WTP and the WTA per sector: Small-Medium Enterprises (SME) and residential households. As for the business, i.e. industry and commercial sector, gross-value-added data from 2011 are used. *Totals* are *a weighted average assuming 40% of domestic consumption, 40% large industrial and commercial sector, and 20% SME* (Walker, Cox, Loughhead, & Roberts, 2014).

Results of the average (or *totals*) VoLL obtained with the different methods are summarized in Figure 11. Results from the survey are shown in more detail in Figure 122Figure 11.

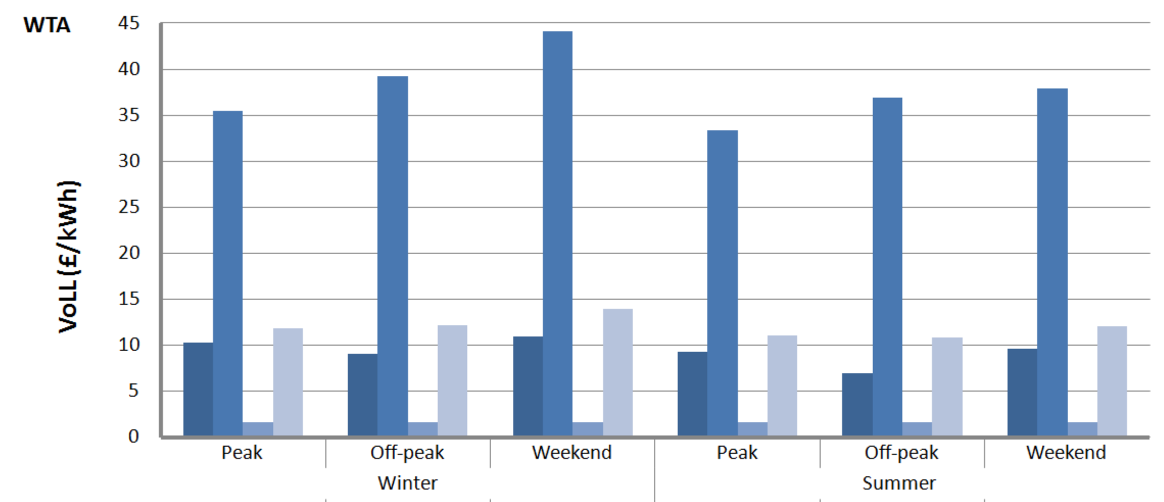
[10] WTA and WTB are defined in Measuring social impact section.

[11] Where peak hours correspond to 3pm-9pm, and weekend values given are off-peak.

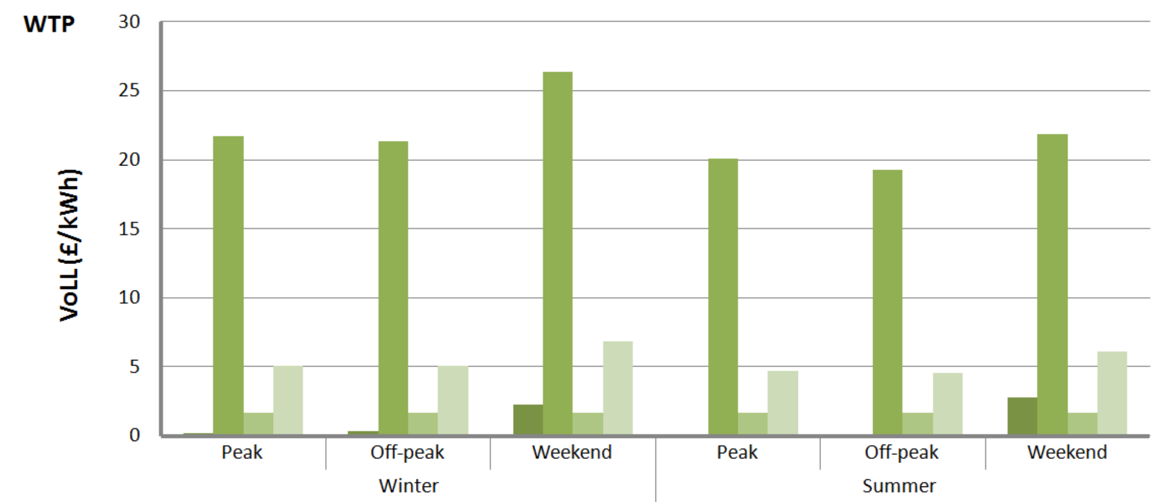


	Winter Peak	Winter Off-peak	Winter Weekend	Summer Peak	Summer Off-peak	Summer Weekend
1 hour	6.49	6.53	5.63	6.27	5.73	5.18
12 hours	4.38	4.96	4.08	3.92	4.43	3.75
WTP	5.08	5.05	6.83	4.71	4.56	6.14
WTA	11.87	12.14	13.88	11.04	10.82	12.07

Figure 11. Average VoLL in 2011 £ per kWh as a function of the season of the year (winter/summer) and the time slot of the day. Different sources are considered: 1-hour or 12-hour average from Blackout Simulator, and total average of WTP and WTA from surveys. Data from (Walker, Cox, Loughhead, & Roberts, 2014)



	Winter Peak	Winter Off-peak	Winter Weekend	Summer Peak	Summer Off-peak	Summer Weekend
Residential	10.29	9.10	10.98	9.26	6.96	9.55
SME	35.49	39.21	44.15	33.36	36.89	37.94
Business	1.65	1.65	1.65	1.65	1.65	1.65
Total	11.87	12.14	13.88	11.04	10.82	12.07



	Winter Peak	Winter Off-peak	Winter Weekend	Summer Peak	Summer Off-peak	Summer Weekend
Residential	0.21	0.32	2.24	0.11	0.10	2.77
SME	21.69	21.33	26.35	20.05	19.27	21.86
Business	1.65	1.65	1.65	1.65	1.65	1.65
Total	5.08	5.05	6.83	4.71	4.56	6.14

Figure 12.Value of Load Lost as a function of the time of the day or weekend and season of the year (winter/summer), estimated from survey results: Willingness to Accept (top panel) and Willingness To Pay (bottom panel). SME corresponds to Small-Medium Enterprises. Business refer to industrial and commercial sector, where gross-value-added was used instead of WTA or WTB. Values are given in 2011 £. Data from (Walker, Cox, Loughhead, & Roberts, 2014).

6.6 Impact on IT Infrastructures

Not considered completely as part of the telecommunication infrastructures, **data centers** (storage and computation) are not exempt of weather-related threats. In comparison to other infrastructures, the impact of Extreme Weather to a Data Centre could spread hitting millions of people around the world and compromising any activity/service **through a variety of digital services** (websites / Clouds / Apps).

As a recent example, in 2012, a series of severe storms caused outages in Amazon's data Center in Northern Virginia (USA) (Slate - Internet Outages Highlight Problem for Cloud Computing: Actual Clouds), (GigaOm - Severe storms cause Amazon Web Services outage) & (CloudTweaks - The Effects Of The Amazon Web Services Outages). This episode caused the Elastic Compute, Elastic Cache (EC2), Elastic MapReduce, and Relational Database Services to be down for a few hours. This impacted several popular sites as Instagram, Netflix, Pinterest and Heroku. All sites were down affecting not only the profits of these companies, but also their users all over the world.

Several actions have been taken by companies to avoid these situations. As example Amazon,

- To prevent the loss of power, increased redundancy and isolation for PLCs so they are insulated from other failures.
- For EC2, avoid the resource saturation that affected API calls at the beginning of the disruption by implementing a better load balancing to quickly take failed API. management service hosts out of production.
- For the Elastic Block Store (EBS), to drastically reduce the long recovery time required to recover stuck or inconsistent EBS volumes when there is a substantial infrastructure disruption.

The estimated cost of a disruption of the service depends on the company (InfoWorld - Calculating the true cost of cloud outages). For example *Amazon.com* could lose almost $5 million for an hour of downtime, the travel service provider Amadeus loses $89.000 per hour during any cloud computing outage, and Paypal could lose around $225.000 per hour.

7 Conclusions

Measuring the impact of failures in E & TC infrastructures is of vital importance to determine investments (on the providers side) or regulations (on the regulatory agencies side) in order to offer a quality and continuous service.

There is a formal, standardized, and well established definition of reliability indices in the electric sector (see Table *2*). On the other side, telecommunication indicators of quality are more recent, in part due to the constant evolution of the services provided. However, regulatory agencies are taking steps on this direction (e.g. the 2009 resolution of the European Parliament described in section Telecommunications sector.

Impact of a disruption of the service is usually assessed in economic terms, being the Value of Lost Load (VoLL) one of the most commonly-accepted measurement. However, social effects are not easily incorporated in impact measurements. The collaboration between economists, engineers, and social specialists would help in quantifying these effects.

Finally, in general, reliability measurements are not directly comparable among countries with dissimilar economies. For instance, VoLL should not be compared without normalization with respect some economic measurement of the country (e.g. GDP).

The majority of networks in developed countries are highly reliable. Therefore, for most of individuals and businesses it seems not worth investing in backup systems, considering the very small probability of disruptions of the service. In these countries, only a small percentage of the users instal a good backup system, and in most cases is obliged by the existing regulations. These regulations mainly affect community service providers like hospitals, or security services.

To sum up, assessing the socioeconomic impacts of outages, and in particular of the effect of major disruptions can serve to *assess the risk and vulnerability of a geographic region and population, evaluate alternative adaptation and risk mitigation strategies, improve decision-making capacities for disaster preparedness and management operations, find the required level of assistance, and inform insurers of their potential liability* (Hasan & Foliente, 2015).

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