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CIPRNet

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Introduction

1.1 Purpose of the document

The objective of this document is threefold:

(i) To present the database (DB hereafter) part of the CIPRNet Decision Support System
(ii) To present the technique used for assessing Vulnerability of the CI elements and
(iii) To present the methods used by the DSS for implementing the consequence analysis.

This document follows the D7.1 where a design study of the Decision Support System (DSS) has been presented. That is the "core" activity of WP7 and all the technologies implemented are functional to the development of this task.

In order to understand where and why the three previously recalled items (which are the objects of the present document) relate to the DSS, it is worth recalling the DSS structure and its main functions.

The DSS, in essence, represents and implements the whole Risk Analysis workflow, spanning from the event prediction and ending with the Impact and Consequences that the predicted event will be able to produce in the system of (inter)dependent CI networks (CI in the following).

The DSS comprises the following building blocks B_i:

- B_1: Monitoring of Natural phenomena
- B_2: Prediction of natural disasters and Event detection
- B_3: Prediction of physical harms scenarios
- B_4: Estimation of impact and consequences
- B_5: Support of efficient strategies for crisis scenarios

The DB is the general repository of all the information (static and dynamic); it is the central part of the entire DSS construction. It has quite many issues to consider (from the security of access as it will contain confidential and strategic data, to an appropriate structure to consider static and dynamic data, to distinguish from national data, to the provision of selected data to specific end-users etc.). Its architecture and technical implementation are a relevant point to ensure the usability of the whole DSS instrument. The DB has a transversal utility all along the DSS Workflow as it contains and stores data and results, which are needed/provided by the different building blocks.

Another relevant point is constituted by the transformation of events manifestation into Damages. This will be done by appropriate vulnerability functions, which, starting from the (predicted or measured) intensity of the natural event will allow the DSS to transform "events intensities" into "CI elements Damages" (in the following we will refer with CI element a physical component of the CI network, as for example a secondary substation for the electrical distribution grid). This activity is central for the B_3 block, which has to transform event's manifestations into Damages.

The third relevant object of the present document is the presentation of a new model, purposely conceived, allowing to transform CI *services unavailability* into Consequences, i.e. the ultimate effects of "well-being reduction" experienced by the whole society (under different viewpoints) induced by loss (or reduction) of the services provided by CI. This is the object of the B_4 block where, after the Impacts assessment (made by a (inter)dependent model of the considered CI) the DSS evaluates the weight of the *crisis*, estimating the *consequences* it would be able to produce according to different viewpoints (called Criteria).

In the following chapters the document will illustrate the previous points.

1.2 Document structure

The document is organised as follows:

- **Chapter 2** presents a detailed analysis of the DB integrated in our DSS. The chapter covers a data ontology that inspired us to build a structure of the DB. Then we present implementation details of the DB and cover aspects related to data security of the DB.
- **Chapter 3** describes the methodology we used to assess the physical vulnerability of CI against specific natural threats and explain how we will investigate this aspect in the future w.r.t additional threats.
- **Chapter 4** describes the methodology used to assess the CI-related Consequences for the different chosen Criteria and the implemented database.
- **ANNEX I** presents a relevant extract of database contents.
- **ANNEX II** presents the logical schema related to the Vulnerability and Impact assessment data.
- **ANNEX III** presents the logical schema related to the Consequence Analysis data.
- **ANNEX IV** presents the metadata scheme for EU Census data (reported the Italian metadata organisation of national Census data).
- **ANNEX V** NACE metadata organisation (NACE: Statistical Classification of Economic Activities in Europe).

1.3 Remarks on terminology

This section introduces the terminology and definitions used throughout the CIPRNet project. Due to its multi-disciplinary nature, the CIPRNet project uses terms from various scientific and technical domains and extends a glossary of terms and definitions started in earlier related projects [2]. The document covers topics in the domains of critical infrastructures (CI) and their protection (CIP), security, safety, some fields within computer science, some CI sectors and more. However, recent developments and the specific nature of CIPRNet require both an extension and an update of the terms and definitions. In particular, existing standards on vocabulary should be taken into account and used.

Terms	*General definition*	*CIPRNet DSS definition meaning*
Anthropic event	An event that is directly consequence of a human action	
Census parcel		A census parcel is the smallest geographic and statistical unit used by a Census Bureau, to which are associated basic demographic data (total population, total number of buildings, etc.). In a city, a census parcel looks like a city block bounded on all sides by streets. Census parcels in suburban and rural areas may be large, irregular, and bounded by a variety of features, such as roads, streams, and transmission lines. In remote areas, census parcels may encompass hundreds of square

		kilometers. [3]
Census indicator		Statistical indicators provide an overview of the social, demographic and economic structure of society. As an example, for population, the main indicators are: (i) Total population; (ii) Population density; (iii) Population by age; etc. There are many indicators for the economy (e.g. GDP), in the employment category and for trade (e.g., exports and imports of goods and services). Other indicators used are those for the environment (Land use, Water supply and consumption, etc.) and for the energy field (Total energy consumption, Primary energy sources, Electricity consumption, etc.). [3]
Consequences		The resulting effects of lack or loss of CI-provided Services measured under the viewpoint of all the considered criteria: economy, population, services, and environment. Consequences could be either produced by the harm itself (oil spill from a drilling platform due to a hurricane), or produced (indirectly) by the Impact affecting CI (like e.g. the interruption of the hospital services is a consequence of the impact on electric distribution produced by the physical damage of an electrical substation).
Consequences Estimate		for the prediction of the ultimate effects produced by Dam- ages and Impacts on different Sectors: (1) Population and citizen's life, (2) Primary Services, (3) Industrial sectors and (4) Environment.
Criteria		Criteria is the generic term for indicating the Societal Life viewpoints under which Impacts (see below) extent are measured. They embrace the effects (a) on citizens (b) on the different Economic Sectors (c) on the Primary Services (Hospital, Schools, and Public Offices etc.) and (d) on the Environment.
Damage Estimate or Damage scenario		Correlating the intensity of the predicted hazards manifestations to the physical harms that those could inflict to CI elements

Event	Occurrence or change of a particular set of circumstances (e.g. a physical failure of a CI component)	
Harm or physical damage		Physical perturbation (or destruction) produced by an event on a CI element (bridge collapse due to an earthquake, short circuit of a telecommunication system due to the flooding of the Telco substation). Here we could adopt even a more specific indication: **Direct harms:** (i.e. bridge collapse due to an earthquake, overload of a transformer due to lightening etc.) when the physical damage is produced directly by the natural hazard **Indirect harms**: in that case where the damage is indirectly produced by the natural hazard: an electrical line breakdown induced by large energy flow associated with an extra electrical demand for air conditioning, for instance, in case of an heat wave. In this case, in fact, the harm is not produced directly by the natural hazard but is produced by a more complex chain of events that, although originating by a natural hazard, cannot (strictly speaking) be considered a direct consequence of it.
Hazard	Source of potential harm (ISO guide 73). Possible source of danger, or conditions physical or operational, that have a capacity to produce a particular type of adverse effects (ISO/PAS 22399:2007)	
Impact		Consequences of the harm at the level of the service provided by the perturbed CI.
Impact Estimate or		Predicting the reduction or loss of Services in a system of (inter)dependent CI
Impact scenario		The set of all the consequences, at the level of Service reduction (or loss) of one or more CI (those directly involved through direct Damages, the others via cascading – or dependency – effects)

Incident	**Event** that might be, or could lead to, an operational interruption, **disruption**, loss, **emergency** or **crisis** (ISO/PAS 22399:2007)	A generic term indicating that something happened producing a perturbation to a given CI
harm	Physical injury or damage to health (ISO 12100:2010)	
Natural Hazard	The potential source of harm based on a natural phenomenon For more detail please refer to UN-ISDR natural hazards classification [UN-ISDR]	The potential source of perturbation to CI originating by natural phenomenon (example: thunderstorm, earthquake, drought, heat wave).
Risk	The combination of the probability of an event and its negative consequences. (UN/ISDR, 2002)	A numerical value enabling to indicate the link connecting the probability of a given natural hazard to the number of consequences that its manifestations might have on CI elements
Threat	Potential cause of an unwanted **incident**, which may result in harm to individuals, a system or organization, the environment or the community (ISO/PAS 22399:2007)	
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards [drm.cenn.org cap5]	The maximum extent (strength) CI components can stand without being structurally (and thus functionally) perturbed by a natural hazard.

2 DSS Database

This section first recalls the DSS architecture, and then it presents a detailed analysis of the DB integrated in our DSS. The section ends with the description of some implementation details of the DB (including data security aspects of the implementation).

2.1 DSS architecture overview

In order to describe the characteristics of the DB, we first recall the architectural design of the DSS. As shown in Figure 1, the DSS consists of four layers:

- **Presentation Layer**: This layer contains the components that implement the different Graphical User Interface (GUI) used by the DSS platform end-users. Such components are based on Geo-Platform, an Open Source Framework of the geoSDI research group ([20]) for creating Rich Web GIS Applications based on geospatial web-based software. The use of Geo-Platform allows building the so-called thin clients that do not require any installation w.r.t. desktop clients. In addition, being based on web browsers, Geo-Platform can also be used without providing admin rights on those networks where software installation may be restricted for security purposes.
- **Service Layer**: This layer contains all modules that realise the DSS business logic. A central component of the Risk Assessment Workflow Module that orchestrates all operations of the local DSS such as the management of the end users and admin requests, the execution of process monitoring and configuration tasks of the Earthquake and Weather Forecast workflows, the implementation of GIS services to allow the visualisation and the manipulation of GIS data.
- **Middleware Layer**: The Middleware Layer implements procedures to gather, on a 24/7 basis, data coming from external sources such as meteorological data needed to feed models and simulations enabling the prediction of future extreme natural hazards. It contains two modules that realise the HPC services and the data access logic. In particular, the Security module implements the availability requirements to ensure that DSS services and data are accessible to final end users even in case of equipment failures. To this end, this component implements a replica of the database servers, and of the file system of the DSS server to obtain a redundant distributed geographically database server as specified in Section 2.3.
- **Persistence Layer**: This layer contains all data to be used within each DSS instance (in general, there will be different DSS instances running for different areas). Each DSS instance may store and/or retrieve these data in different databases: (i) a public GIS-Data DB storing the GIS layers compliant to INSPIRE [6] and OGC standards [4] such as territorial, socio-economical, technological infrastructure data; (ii) a private Local-DSS DB containing custom information specific for each DSS instance (e.g. the Geo-Platform users and projects); (iii) an EISAC DB containing data information common to all DSS instances and (iv) a set of External DBs to retrieve data that can be accessed outside the DSS-instance via specific protocols and interoperability standards (e.g. OCG standards for GIS data).

Each DSS instance allows storing data requiring different frequencies operation update. For example, the number of people living in a specific area need to be updated once each a year whilst the historical events layer data (e.g., the earthquakes events in a specific area) needs to be updated with a frequency of minutes or hours. The update procedures are performed using different modalities depending on data availability and update frequency requirement. In some cases, the data updating operations depend on authorised data scraping automated procedures.

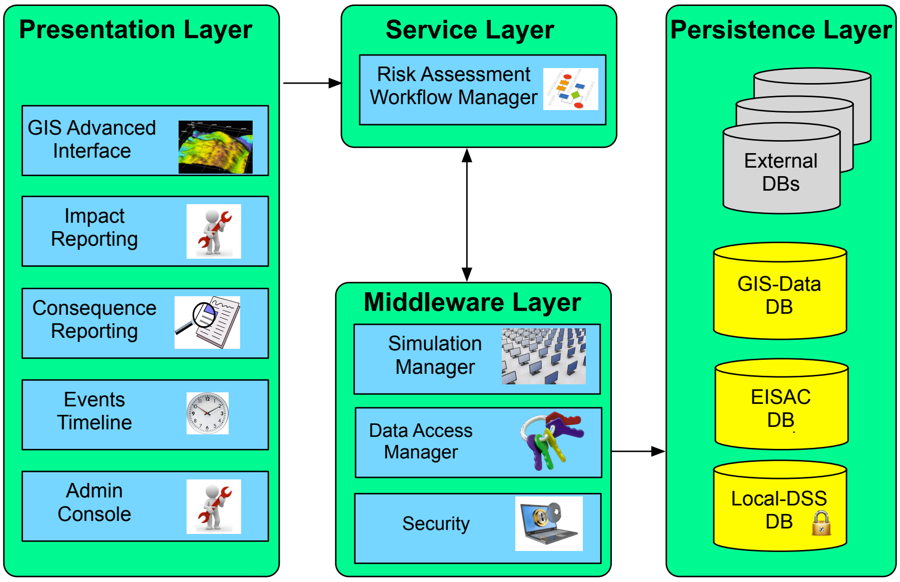

Figure 1: DSS 4-tier architecture diagram.

2.2 Data ontology

The DB is conceived and organised to store information and geospatial data, as specific GIS layers (compliant to INSPIRE and OGC standards). The data stored within the DB can be classified into different groups, according to their typology and to their exploitation within the DSS workflow (Figure 2):

- **Basic data**: used as base-layers for the DSS geographical interface and as input layers for spatial analysis and processing;
- **Processed data**: including the results of the data processing i.e., the damage scenario, the impact estimate and the consequence estimate data.

In turn, each group contains different pre-defined categories of data.

In particular, as "Basic Data" the following categories are considered:

- Territorial layers and maps
- Socio-economical
- Historical events
- Technological Infrastructure
- Quasi-real time data

The list of data currently stored into the DSS DB (along with relative sources and other ancillary information) is reported in ANNEX I.

The sources of data can be governmental repositories (e.g. the national GIS repositories as the Italian SINANET site, the Italian National Institute of Statistics – ISTAT, etc.), infrastructure operators, data coming from simulation models (as the wheatear forecast), etc.

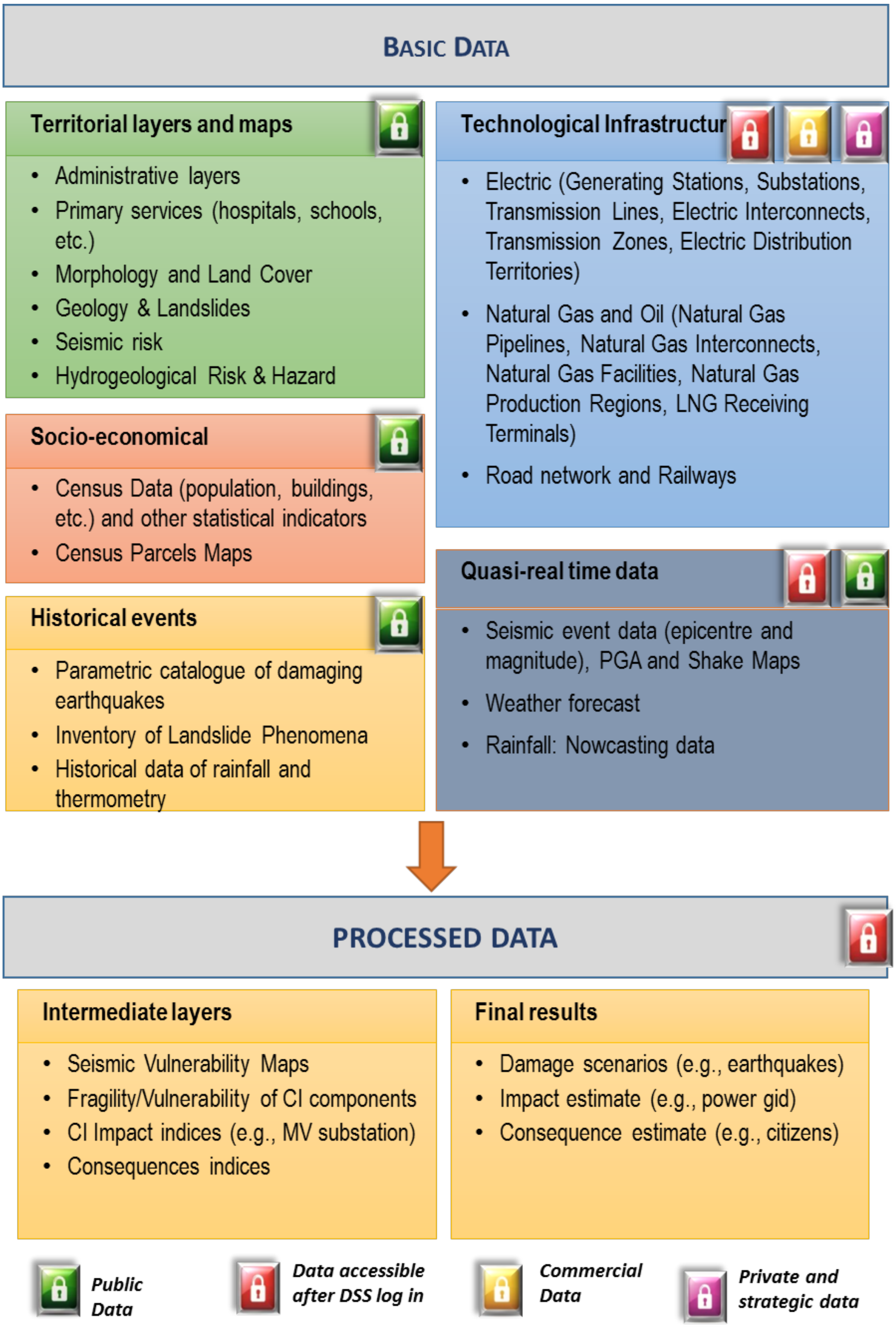

Figure 2: DSS Database. Data ontology with data ontology instances samples.

In general, the data stored within the DSS DB require different frequency of update operations. For instance, the number of people living in a specific area need to be updated once each a year whilst the historical events layer data (e.g. the earthquakes events in a specific area) needs to be updated with a frequency of minutes. The update procedures will be performed using different modalities depending on data availability and update frequency requirement. In some case the data updating operations will depend on authorised data scraping automated procedures.

2.3 Database security

In this Section, we discuss the security aspects of the DB used by the DSS. As remarked in [5], the issue of implementing a secure database architecture is required so that any data flows between the stakeholders can have associated controls based on type of data (personal or not), who processed it (data collector), operating platform, processing application, purpose of processing, protection mode, storage lifetime, who provide the sources (data provider) and to whom the data will be disclosed (end user) transferred and at which location it will be stored.

2.3.1 Database and server security architecture

The DB servers consist of the GIS-data DB, the Local-DSS DB and the EISAC DB servers. The GIS-Information DB will be based on PostGIS DBMS v.2.x to manage GIS data whereas the other DBs will be based on Postgres DBMS v.9.2. Both databases do not contain any personal data.

Figure 3 shows the deployment diagram showing the connection between the DSS server running the Risk Assessment workflow (B_1-B_5 blocks) and the different instances of the DBs. All the servers are hosted in the ENEA UTMEA Computer Centre. Such a centre has the following characteristics:

- The hardware and frameworks are hosted in a locked room where only authorised ENEA staff members can enter;
- The computer centre is equipped with a fire system and UPS system.

Moreover, as shown in the Figure 3, the ENEA UTMEA building provides physical security, as it is located inside the ENEA Casaccia Research Centre, a 24/7 access controlled Centre equipped with a system of doubled high security fence.

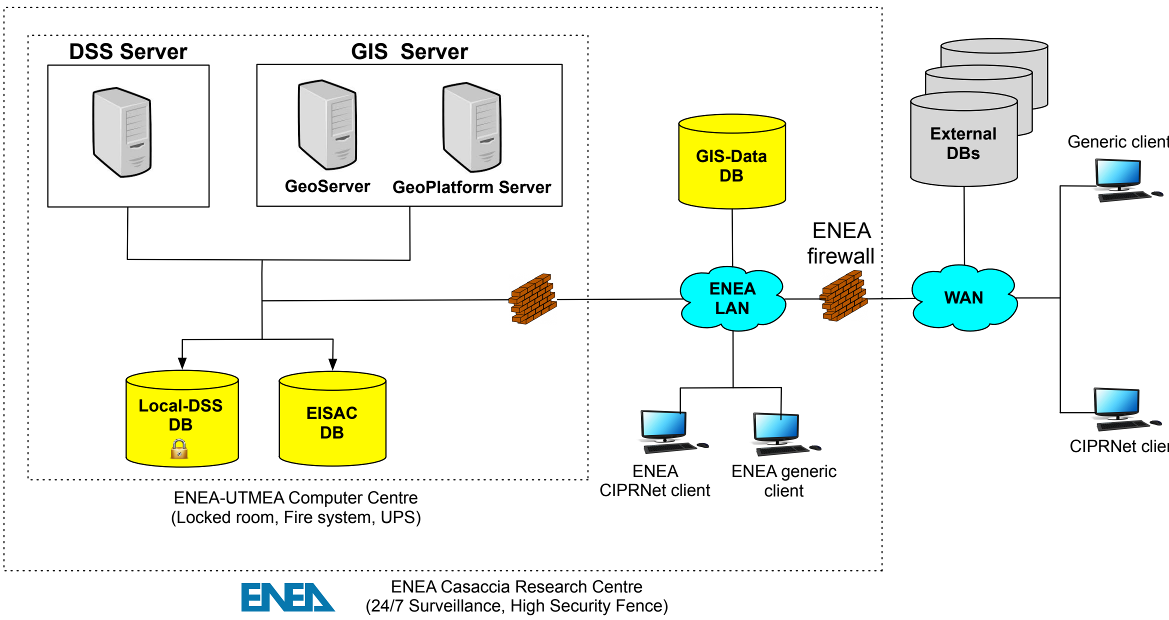

Figure 3: Deployment diagram of the DSS servers.

The ENEA server configuration is compliant with the basic physical security requirements. Regarding network access control requirements, the DSS servers and the CIPRNet Private DB are protected by two firewalls:

- The CIPRNet servers software-based firewalls;
- By the ENEA Casaccia firewall and monitoring systems that constitutes the main barrier to ensure access control to CIPRNet data and systems.

Another relevant aspect in information security is the availability requirements to ensure that DSS services and data will be accessible as much as possible (in general the availability requirements are specified through minimum acceptable thresholds percentage of the time the service is available) to final end users even in case of equipment failures.

In the following, the solution adopted for the Italian CIPRNet DSS instance for data and services replication will be described. Figure 4 shows the master/slave CIPRNet DSS configuration. In particular, this configuration envisages the set-up of a replica of database servers, file system as well as the other DSS services.

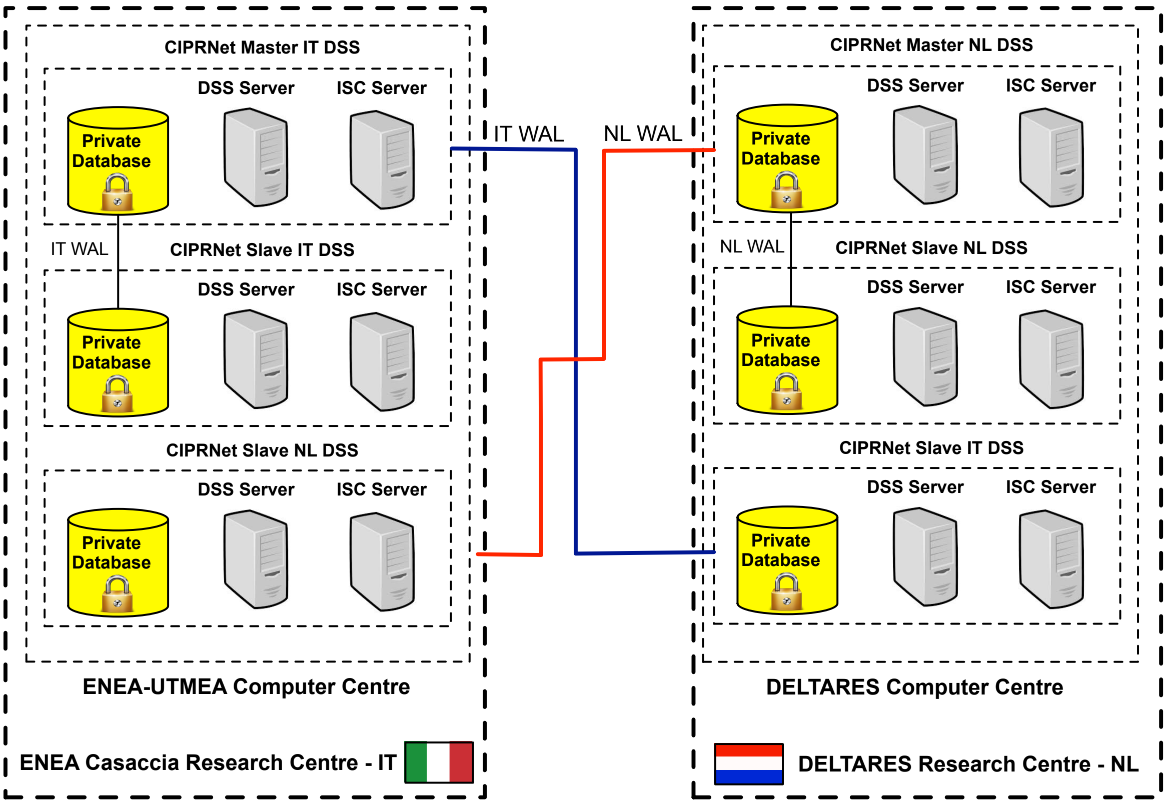

Figure 4: Master/Slave configuration and geographically distributed replication schema.

In the described configuration, only the master or the primary server can modify data. The slave is managed as a warm standby server, that is, it cannot be accessed until it is promoted master (another possible solution would be to have hot standby server, that is, it can accept connections and serves read-only queries). In order to guarantee the synchronisation and the coherence of the database replica, the adopted solution will make use of Transaction Log Shipping methodology. Using this technique, the warm server is kept current by reading a stream of write-ahead log (WAL) records. In particular, the master server sent to the slave server log files containing all transactions that have been performed in the master database. In case of failure, the slave database server can use the log file to update the slave database with the last logged transactions. In general, this replica solution can be applied to manage redundant distributed geographically database servers (Figure 3). For example, for the Italian DSS instance the standby servers may be hosted in the Deltares (The Netherlands) research centre. Then, the Italian DSS may be operative even in the case the ENEA UTMEA Computer Centre is totally not operative.

2.3.2 Database security analysis report

The components that build the DSS servers infrastructure have been analysed against vulnerabilities that could be exploited to convey cyber-attacks. This activity was performed with the support of the Institute of Telecommunications of the University of Technology Poland (UTP) for their long-lasting experience in Cyber Security.

The objectives of the analysis were:

- To identify the security level of databases,
- To identify the security level of interfaces that allows to manipulate the data within the database,
- To identify the security level of information channels that are used to transport data from database to remote clients,
- To identify direct and indirect impact of the identified vulnerabilities.

In many cases majority of adapted components like frameworks, libraries, application interfaces (APIs), data storages, etc. are usually delivered by third parties. Therefore, it is important to identify those vulnerabilities that are related to flaws located in source code of such components, because it gives an overview on how reliable a given component is and allows understanding what is the involved risk. Furthermore, the process of bug fixing in third-party elements may be problematic and impact all DSS service.

During the analysis we particularly focused on cyber-attacks related to application layer, because those have the ability to bypass the firewalls located in lower layers. This steams from the fact that these attacks are conveyed using communication channel that are allowed by firewalls. Moreover, the list of top 10 most critical risks related to security of distributed systems, provided by OWASP (Open Web Application Security Project) indicates application layer attacks as serious threats. Factors, such as easy exploit-ability and severe impact of potential attacks are mentioned as the most crucial, because successful attack can cause serious consequences including data loss, corruption, and lack of accountability or denial of access. The most common attacks that are identified in application layer are:

- Cross Site Scripting (XSS) – these kinds of attack exploit software flaws that are related to improper validation of user input. These flaws allow the attacker to store in attacked database arbitrary code that could be downloaded and interpreted by client side. Therefore, these attacks can impact indirectly the security of the database. For instance, vulnerable to XSS attacks server allows the attacker to steal sensitive data from client or deploy malicious software on client side.
- SQL Injection Attacks – are also related to improper user input validation. These kinds of attacks allow the attacker to execute arbitrary code on the database. Therefore, these can directly impact the security and integrity of stored data.
- Attacks exploiting improper session management – these kinds of attacks use access control and configuration flaws to invoke unauthorised function on a server side. Moreover, the unsecured communication or poorly implemented session management mechanisms allow the attacker to hijack the session (e.g. stealing the session id) of legitimate users. As result, this indirectly may impact the integrity and security of the database.

- Man-in-the-middle Attacks – can also impact indirectly the security of database, allowing the attacker to intercept the traffic coming from client, modify it, and send it to the server.

During the analysis for the system design shown in Figure 3 it has been identified that the GeoServer (version 2.4.4 and lower) is vulnerable to XSS attacks (the exploit is shown in Figure 5). Therefore, the recommendation here was to upgrade the version 2.4.5.

```
2   src/wms/src/main/java/org/geoserver/wms/WMSServiceExceptionHandler.java

@@ -276,7 +276,7 @@ public void handleXmlException(ServiceException exception, Request request) {
276 276
277 277         // exception locator
278 278         if ((exception.getLocator() != null) && !exception.getLocator().equals("")) {
279     -           sb.append(" locator=\"" + exception.getLocator() + "\"");
    279 +           sb.append(" locator=\"" + ResponseUtils.encodeXML(exception.getLocator()) + "\"");
280 280         }
281 281
282 282         sb.append(">");
```

Figure 5: The XSS exploit in GeoServer v2.4.4.

The analysis have also shown that default configuration of the GeoServer allows the attacker to convey Man-in-the-middle attacks and intercept user credential. Example of eavesdropped request is shown in Figure 6.

```
POST http://192.107.77.21:8080/geoserver/j_spring_security_check HTTP/1.1
User-Agent: Mozilla/5.0 (Windows NT 6.2; WOW64; rv:32.0) Gecko/20100101 Firefox/32.0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: pl,en-US;q=0.7,en;q=0.3
Referer: http://192.107.77.21:8080/geoserver/web/
Cookie: JSESSIONID=65F8096EB1F2CE63F2390660C3985A98
Connection: keep-alive
Content-Type: application/x-www-form-urlencoded
Content-Length: 29
Host: 192.107.77.21:8080

username=User&password=Secret
```

Figure 6: Intercepted HTTP request with user credentials.

The recommendation in this case was to either encrypt the communication between client and the server or allow the access to the GeoServer front-end only from a local network.

During the security evaluation tests also the graphical user interfaces (GUIs) have been analysed. The results allowed us to identify potential exploits that among others would enable the attacker to retrieve sensitive data, bypass access control mechanisms, inject malicious code, or hijack session of legitimate user. More extensive results of conveyed penetration test have presented in [7].

3 Vulnerability and Impact Assessment

A variety of events, both natural and man-made, can affect CI and cause outages. Widespread outages or power shortages lasting days or more are unlikely to occur unless significant components of the bulk power system generation and transmission are damaged [8]. According to the available literature [9], long-lasting outages of multi-circuit transmission facilities can originate by very strong earthquakes or severe storms. The DSS will be able to analyse the following natural hazards:

- Earthquakes
- Abundant rainfalls
- Heat/Cold waves
- Strong Winds
- Lightening
- Heavy snowfall
- Ice
- Landslide
- Flash flood
- Flooding
- Mud flows
- Debris avalanches
- Storm surges

Each DSS instances may implement special and detailed workflows for specific natural hazards depending on the reference area data availability and priorities (e.g. the DSS instance running in The Netherlands may implement specific and detailed workflows for the flooding hazards to exploit data availability and previous expertise in this area).

The DSS will provide a comprehensive ("all hazards") evaluation of natural threats and also Simulation applications where synthetic natural events (earthquakes, heat and cold waves, abundant rainfalls) are reproduced and the resulting potential Damages estimated.

In the following, we present methodologies to assess the vulnerability of physical components of CI and show how we used them to produce vulnerability values for the scenario of infrastructures considered in the DSS. In particular, we show how we designed specific data models to store such data in the CIPRNet DSS DB. In particular, we will show the proposed vulnerability assessment methodologies applied to two specific CI networks: the electrical distribution grid of Rome and a portion of the Rome telecommunication mobile network. Indeed, we use CI data collected from the main utilities operating in the city of Rome in the electrical distribution and telecommunication domain.

3.1 Threats and vulnerability matrices

The DSS is able to predict, within a specific time frame, the strength of a set of natural phenomena occurring in a given area and to estimate the resulting Physical Harm Scenario (PHS). Such functionalities, provided by the functional blocks B_2 and B_3, use specific matrices that are stored in the DB to evaluate the intensity of a natural threat and the vulnerability of physical components to such threats.

The first matrix, called **threat matrix**, stores for each natural hazard T_j its expected probability of occurrence $P(T_j)$ together with its strength s_j measured with the usual units (e.g. for T_j representing a seismic event, the relative strength measured as a Peak Ground Acceleration may be 0.5 m/s^2 for a severe event; strong wind will be classified in the Beaufort scale etc.).

Further, in order to consider an equal strength scale for all threat manifestations T_j with strength s_j, we will define a specific metric function *F*, called "strength transformation" s.t.

$$F: (s_j) \rightarrow [1,5]$$

Equation 1: Strength transformation (from a continuous to a discrete strength scale).

which transforms the effective strength of the hazard into a phenomenological scale containing 5 levels (from 1 to 5). The strength transformation function allows, for each threat manifestation s_j, to define a scale of phenomena manifestation that predicts a given environmental situation at a given time t.

Using for all threat's manifestations such a transformation function *F*, it is possible to define a Threat matrix *S(r,t)* that estimates, given a specific location ***r*** and a specific time ***t***, which will be the strength of the one (or more) event predicted to occur at that time on that specific location (location where one or more CI elements could reside). Thus

$$S(r,t) = S(T_j, F_j)$$

Equation 2: Threat matrix.

Based on a similar reasoning, it is possible to define a **Vulnerability matrix** *V* that is a function of the specific element C_i, accounting for the maximum perturbation strength (produced by the different threats) it could sustain before a physical failure:

$$V[C_i(r,t)] = V(T_j, F_j)$$

Equation 3: Vulnerability matrix.

Both matrices have the same dimensions: in the row, they have all the different threats (see list from (1) to (13) above) which the system is able to recognise and in the columns the predicted strength of the specific event. The Strength Matrix element reports the effective predicted strength at a specific location (if the event ***i*** is predicted to occur with a grade 3, the element S_{i3}=1). The Vulnerability Matrix element reports that is the threshold at which the element C_i is predicted to be disrupted, for a specific event. If for instance, the element C_i is supposed to be disrupted, by event ***i***, by a strength 3, the matrix values V_{i3}, V_{i4} and V_{i5} will be set equal to 1. In fact, if the CI element would be disrupted by a strength 3 threat (incident), *a fortiori* it will be disrupted by the higher strengths 4 and 5). The same CI elements, indeed, could be disrupted by different events, each of them acting on it at a different strength. Thus the same elements could be disrupted by event ***i*** from grade 3 on and by event ***j*** from grade 4 on.

The physical damage probability to which an element C_i of the x-th CI is submitted by the threat(s) j will be given by overlying the two matrices S and V:

$$D_{ij}^{x} = \max\{\ S(T_i, F_i)\, V(C_i, T_j)\}$$

Equation 4: Physical damage probability.

When the specific threat T_j manifests with strength higher than the specific Vulnerability threshold D_{ij}^{x} of the element C_i, the element will be supposed to fail. The maximum function will select the highest level of failure induced to the C_i element by a threat (in the case where many threats simultaneously hit the element).

Thus, if D is greater than a specific threshold (e.g., 0.6) then the element is predicted to fail. The set of all D greater than the fixed threshold will constitute the PHS, which will be provided to the CI operators as alert information.

This methodology has been previously described in [1].

3.2 Vulnerability analysis

Whether the identification of the terms of the Strength Matrix is straightforward once having defined the ***F*** function (see Equation 1), the problem of defining the Vulnerability Matrix for each element of a given CI (and for all the CI) and for all the natural threats is much more complex. In all cases, historical data and specific perturbation/disruption analysis can be used to infer specific failure thresholds.

In the following, we present the methodology, which allows the construction of a Vulnerability model for CI to transform manifestations strength into damages for the different natural threats considered. In particular, two different options have been considered in our approach for the definition of Vulnerability indices to characterise the response of the different CI elements to the different natural threats:

a) Inferring vulnerability thresholds from historical data (wherever available);
b) Considering vulnerability thresholds from technical data sheet of CI elements.

Option a) is useful and feasible when natural events with “large” statistics are concerned. For other events (black swans), the specific manifestations of occurrence will be transformed in a specific stress (like e.g. structural stress for strong winds) and related to the breaking load of the specific component taken by datasheet (b1 option). In other cases (like e.g. earthquakes) we will rely on well-assessed literature data providing empirical relations between GPA (ground peak accelerations) and the fragility of the buildings, considering their technical data (age of building, number of floors, construction technique etc.) (b2 option)

Concerning (a), the use of historical data allows adopting two approaches leading to complementary information:

(**a1**) The evaluation of vulnerability index of “special” CI elements that unambiguously show correlations with the occurrence of specific events (e.g. electrical cabins whose outages have been recorded (predominantly) under specific conditions);

(**a2**) A generic vulnerability index relating the vulnerability of a class of CI elements to a specific natural threat, as a function of the intensity of that threat (like e.g. the probability of having an electrical cabin faulted as a function of the maximal temperature recorded in the day of outage).

Our Vulnerability analysis mostly relies on historical fault data (**a** option). To this regard, we obtained some historical data of the faults of CI apparatuses from CI operators (in the electrical end telecommunication domains) and correlated with publicly available weather data (and the historical time line of the events occurred in a given place). Thus we mostly refer to this method (correlation from historical log data) and we evaluated either (**a1**) and (**a2**) option indices.

Table 1 reports a summary of the natural threats analysed according to the specified options.

Table 1: Summary of the methods for vulnerability analysis (Yellow boxes: done, grey boxes: to be done).

Natural threat	Historical fault data method (a1 and a2 options)	Data sheet method (b1 option)	Analytical based method (b2 option)
Earthquakes	X		X
Abundant rainfalls	X		
Heat/Cold waves	X		
Strong Winds		X	
Lightening		X	
Heavy snowfall	X		
Ice	X		
Landslide	X		
Flash flood	X		
Flooding	X		
Mud flows	X		
Debris avalanches	X		
Storm surges	X		

In the following section we will describe the work that has been done regarding the option a) for vulnerability assessment. In further documents, the on-going work for option b) will be described.

3.2.1 Vulnerability: a) method

The most appropriate historical data usable to infer vulnerability indices are those related to CI elements faults. Although these data contain also failure induced by common causes, correlation analyses between failures and occurrence of natural threats can unveil how much that specific perturbation is able to transform stochastic faults into natural event-induced fault. However, the inclusion of stochastic causes of failure into our analysis reinforces the value of the Vulnerability index that empirically takes into account also the occurrence of common-cause failures that, indeed, also affect CI operation and can undermine their functionality.

The analyses under the **(a)** option are carried out as follows.

On one side, we have an historical fault log file indicating when (date, hour of the day) the CI element has failed and the overall duration of the failure. On the other side, we have collected the historical events occurred daily for as many years as those represented in the fault log file (precipitations, temperatures, occurrence of specific accidents such as flooding, landslide etc.). An appropriate combination of these data, allows vulnerability indices to be extracted for the considered CI elements.

As there are a few points where events data are recorded (like e.g. rain gauge or weather cabins) and much more points where CI elements are located, each CI elements will be thought to have experienced the events with a strength recorded in the closest observation point: the CI element located to point ***r*** is likely to have experienced the weather-related events as they have been recorded in the closest weather station.

In order to explain this method, we have gathered data from several rain gauges and thermometric stations respectively located in the area of Rome. The considered data cover the period

2010-2013. Each rain gauge or thermometric station has been associated to a number of electrical substations so that all the electric substations covered by a specific rain gauge or thermometric station were considered to exhibit the same physical quantity of the natural threat i.e., the same water level (expressed as mm of water) and temperature (expressed as Celsius grades) measured from those instruments.

Figure 7 shows the different rain gauges considered and the relative areas with the associated substations. In order to compute the mean areal precipitation and thus to build the different areas associated to each rain gauge, we used the Thiessen Polygon method.

In general, Thiessen polygons also known as Voronoi polygons or Voronoi diagrams [18] are an essential method for the analysis of proximity and neighbourhood. Thiessen polygons are generated from a set of sample points and are used to allocate space to the nearest point feature. Each polygon defines an area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points.

Specifically referring to the precipitation computation, this method assigns an area (that is a Thiessen polygon) to each rain gauge. The Thiessen polygon is the region for which if we choose any point at random in the polygon, that point is closer to this particular rain gauge than to any other rain gauge. In effect, the precipitation surface is assumed to be constant and equal to the rain gauge value throughout the region.

Thiessen polygons are constructed according a geometrical approach: a polygon encloses all the space which is closer to the associated centre than to any other point and the borders of polygons are the geometric places, which have the same distance to two centres. In order to construct Thiessen polygons, all the points are triangulated into a triangulated irregular network. For each triangle edge, the perpendicular bisectors are generated, which form the edges of the Thiessen polygons. The perpendicular bisectors are constructed by means of drawing circles with radius d around the corresponding points. The vertices of the Thiessen polygon are at the location at which the bisectors intersect (see Figure 7). A Thiessen partitioning of the city of Roma has been performed around the Official rain gauges and the weather stations of the City Council.

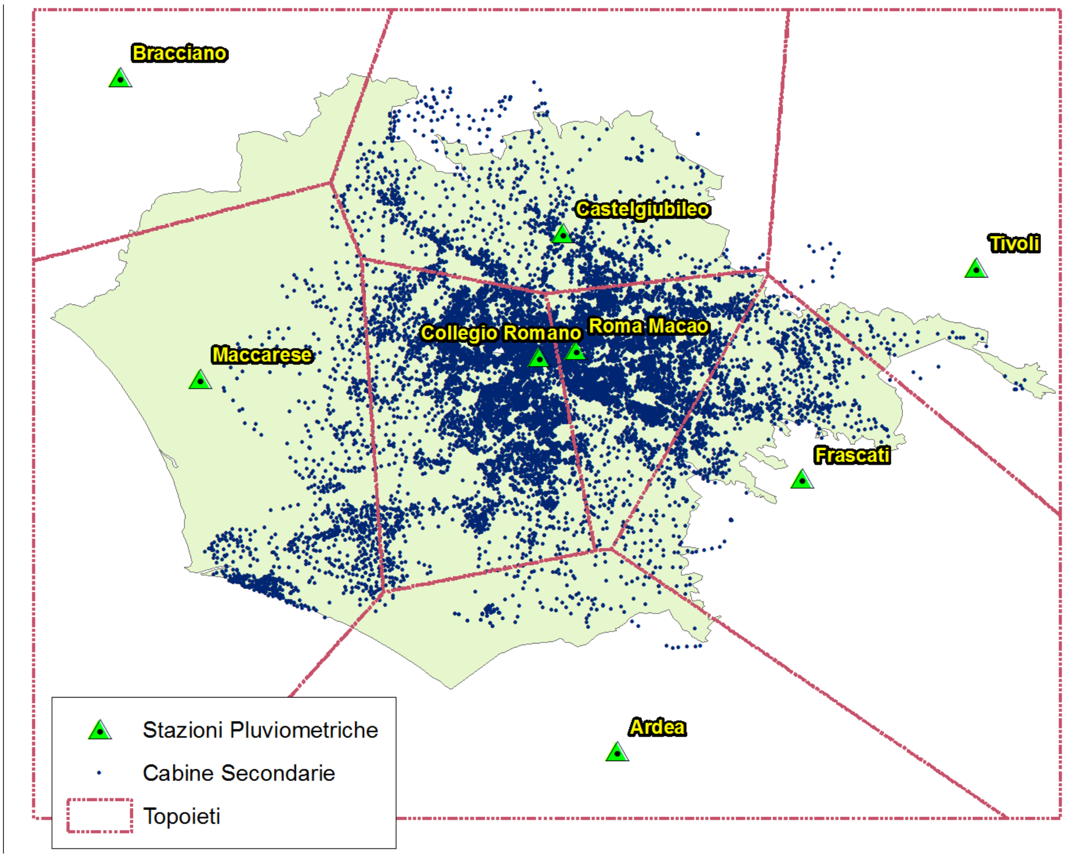

Figure 7: Rain gauges, the position of the electrical secondary substations and the Thiessen partitioning.

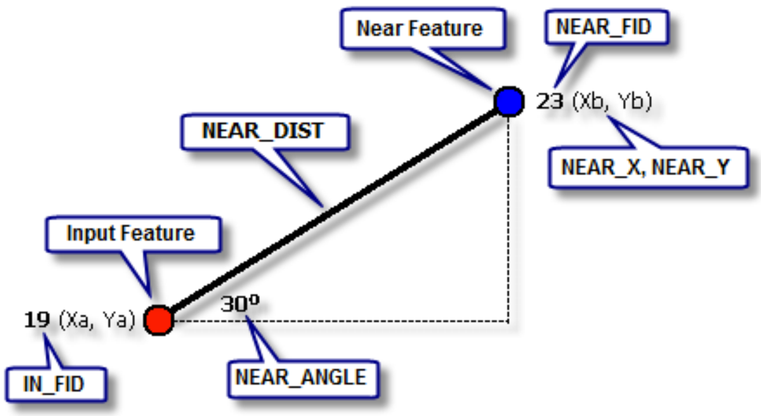

Figure 8: Distance between the secondary substation and the closest weather station providing temperature data.

In order to build the different areas associated to each thermometric station, we considered a minimum distance based method so that each Secondary Substation is connected to the closest Thermometric Station (Figure 8). This measurement was performed by means a geo-processing procedure that, by calculating all the possible distances, selects the one where the two features are closest (the straight line connecting the points). Figure 9 shows the considered weather stations (allowing temperatures data) and the relative areas with the associated substations.

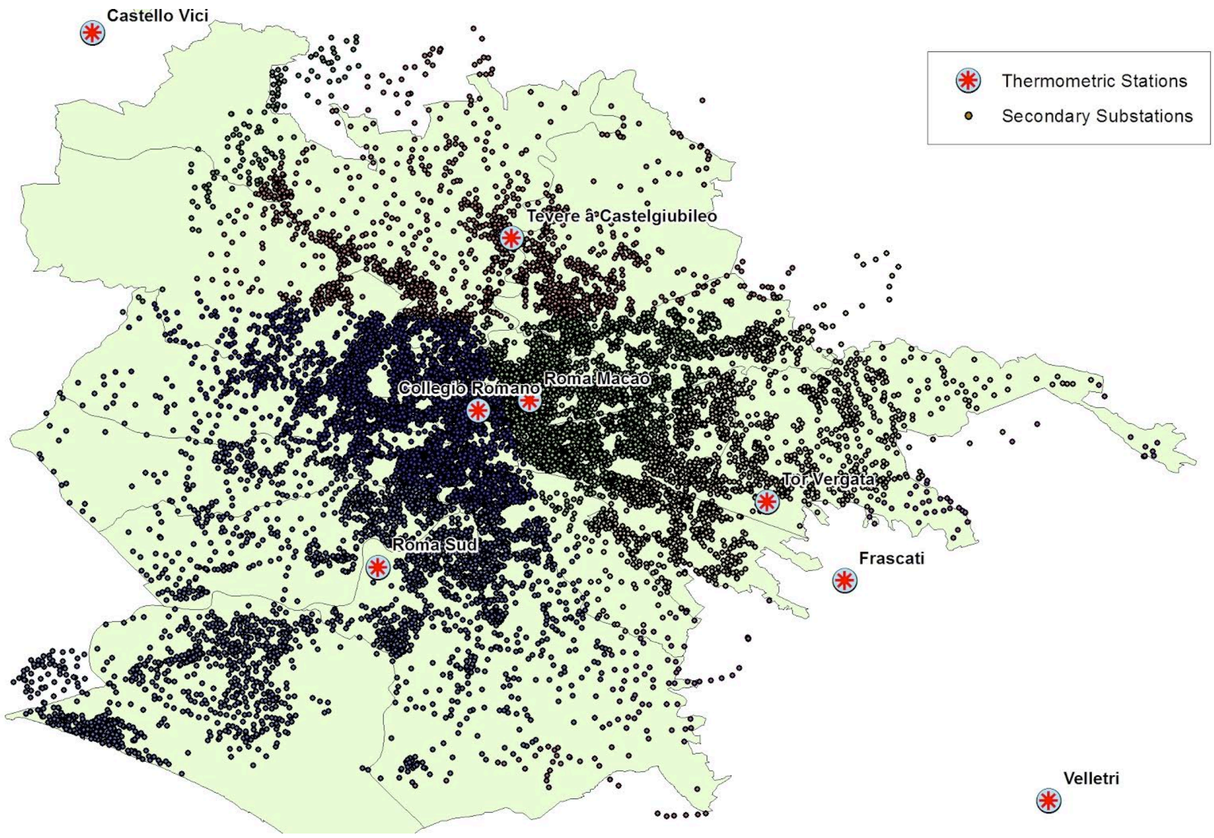

Figure 9: Weather stations considered in the statistical analysis.

As previously indicated, the (a) option can be used to extract two types of information:

(a1) concerning the exploration of specific CI elements whose faults history is very much correlated to a specific event (i.e. abundant rainfalls, hot wave etc.)

(a2) concerning the generic behaviour of the set of CI elements versus the occurrence of a specific manifestation (rainfall, heat waves etc.)

In order to extract the (a1) option vulnerability index, we have evaluated the following formula. Given

- n_f is the number of times the CI elements failed in a specific weather condition
- n_t is the total number of times the CI elements failed

if we define

$$V_1 = n_f^2/n_t$$

Equation 5: Specific vulnerability index.

the value of V_1 will be much larger than unity if the failure of the CI elements have been mostly related to the occurrence of given events; low values of V_1 indicate, in turn, a low correlation with the specific event.

As it will be shown in the following, we have used the V_1 index in both abundant rainfalls and hot waves in order to locate CI elements (of the electrical distribution network) showing very large V_1 values and thus a strong propensity to be affected by the recurrence of the specific weather conditions.

In order to extract the (a2) option vulnerability index V_2, in turn, we have evaluated the distribution function of the number of faulted CI elements as a function of the occurrence of a specific event manifestation of a given strength. For instance, we have evaluated the distribution of faulted electrical cabin as a function of the rain quantity fallen in a specific day.

This analysis results in a point distribution that has been then treated by using non-linear regression analysis to extract from data a general formulation allowing to connect the number of faults as a functions of the strength of a given perturbation. We have applied this method for assessing vulnerability V2 of the electrical cabins as a function of (i) the quantity of rain precipitation occurred in one day in the area of the substation and (ii) the hottest temperature of the day.

3.3 Vulnerability to specific natural hazards

Although the method that we have designed to estimate the vulnerability index applies for (essentially) all types of perturbations, the current availability of a specific "climatological" data available in a Mediterranean area allowed us to access (to date) only specific classes of natural hazards. Mild (or not particularly cold) climate present to these latitudes inhibited the analysis of, for instance, cold waves related faults, or related to ice presence or to that of strong winds (typhoon or similar events).

However, this method could be re-applied to set of data (historical weather data and the related historical faults data log) when available, allowing the extraction of the related vulnerability indices.

In the following sections, we will attempt to extract information based on available data on several (quite relevant and frequent) natural events that mostly affect countries at our latitudes. In particular, to explain the general methodology, the following sections describe the vulnerability analysis of electrical distribution stations w.r.t to different natural events. The proposed methodological framework can be applied for any CI components. The only limiting factor to the applicability of the methodology is the availability of historical failures data of the different CI components (at the moment, the database stores failure historical data related to the electrical distribution grid in Rome).

3.3.1 Abundant Rainfalls

Two analyses have been carried out: the V_1 index, and the V_2 distribution function.

To provide the V_1 index (Equation 5) we have restrained the search of correlation when perturbation strength (in this case the total amount of rain fallen during the day r_d>20 mm). Figure 10 reports the resulting data: in different blue colours we have reported the stations showing a V_1 >2 (analysis of an historical fault data 2010-2013).

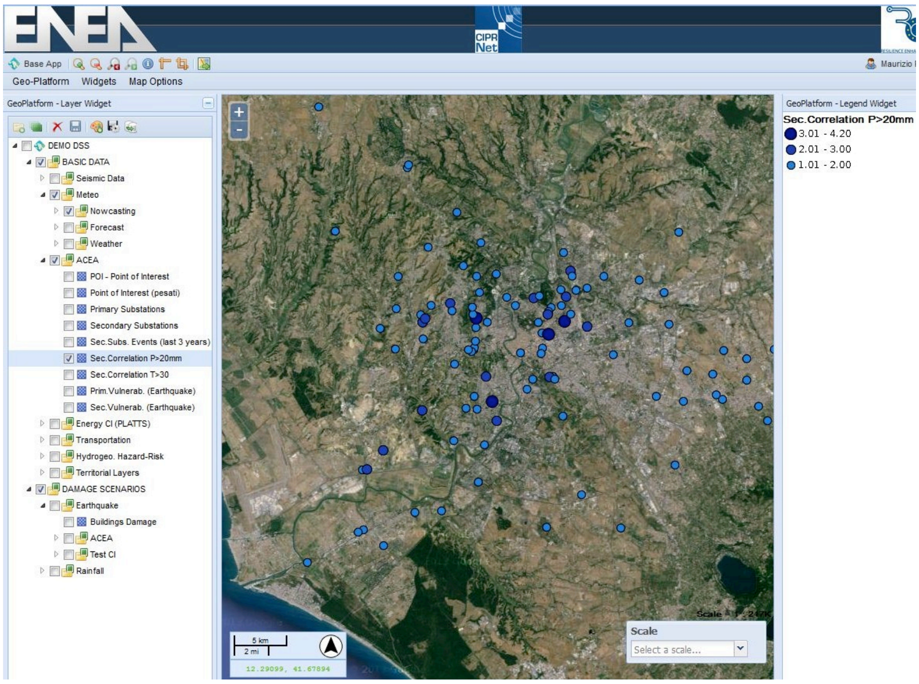

Figure 10: Electrical substations vulnerable to rain level > 30 mm.

As far as the V_2 distribution is concerned, the results of the analysis pointed on a point distribution as reported in Figure 11 (blue dots). The red curve represents the best curve fitting of the data set.

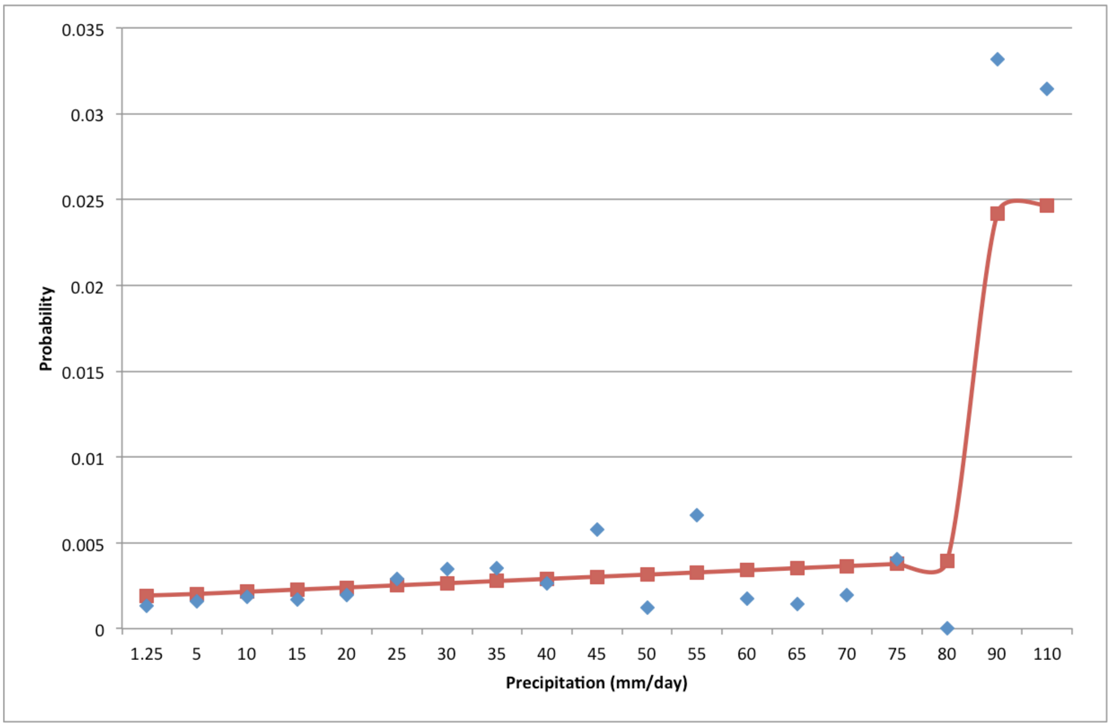

Figure 11: Vulnerability of Electrical Secondary substations to heavy rainfalls. In abscissa, the mm rain felt during a day and the probability that the substation (experiencing locally that rain amount) goes in a fault state.

Starting from this finding, we have attempted to generate a functional form of the fitting curve, which could be a valid paradigm for interpreting the general results of this type of estimate. We expect that a vulnerability curve could consist of two behaviours: a linear behaviour for small perturbations and a non-linear behaviour for severe perturbations (threshold phenomena).

The data points of Figure 11 confirm this finding. Light rainfalls (r_d < 40-50 mm rain per day) seem to slightly (and almost linearly) increase the number of total faults (the total number of electrical cabin which provided the database is more than 13.000 for a period of 4 years). At r_d > 80 mm rain per day, in turn, there is a huge increase of the number of detected faults, as if this figure would constitute a threshold for the take-off of a different response behaviour of the set of electrical stations and the specific perturbation.

This type of behaviour (linear at small perturbation strength and then highly non-linear, above a specific threshold) could be thought as paradigmatic; this mixed functional form is able to capture the behaviour of the probability function of being damaged with respect to the perturbation intensity.

In general such a curve can be expressed as follows (***f*** is a Probability, ***x*** the precipitation strength in the scale 1–5 (as expected for the Vulnerability matrices), α, β, γ and δ free parameters to be adjusted on the specific case, related to historical events):

$$f(x) = \alpha x + \gamma + \delta\, tgh(x - \beta)$$

Equation 6: Generic Fault Probability equation.

The free parameters of Equation 6 could be fixed by imposing the following constraints:

$f(0) = 0, f(5) = 1$

This yields the following parametric values for δ and γ

$$\delta = \frac{1 - 5\alpha}{tgh(5 - \beta) - tgh(-\beta)}$$

$$\gamma = \frac{(1 - 5\alpha)tgh(-\beta)}{tgh(5 - \beta) - tgh(-\beta)}$$

The values of α and β should be defined by fitting historical data.

Table 2: Threat and vulnerability metric.

Threat intensity	5 mm	20 mm	35 mm	55 mm	80 mm
Threat level T_i	1	2	3	4	5
Physical vulnerability V_i	0.2	0.3	0.6	0.75	0.9

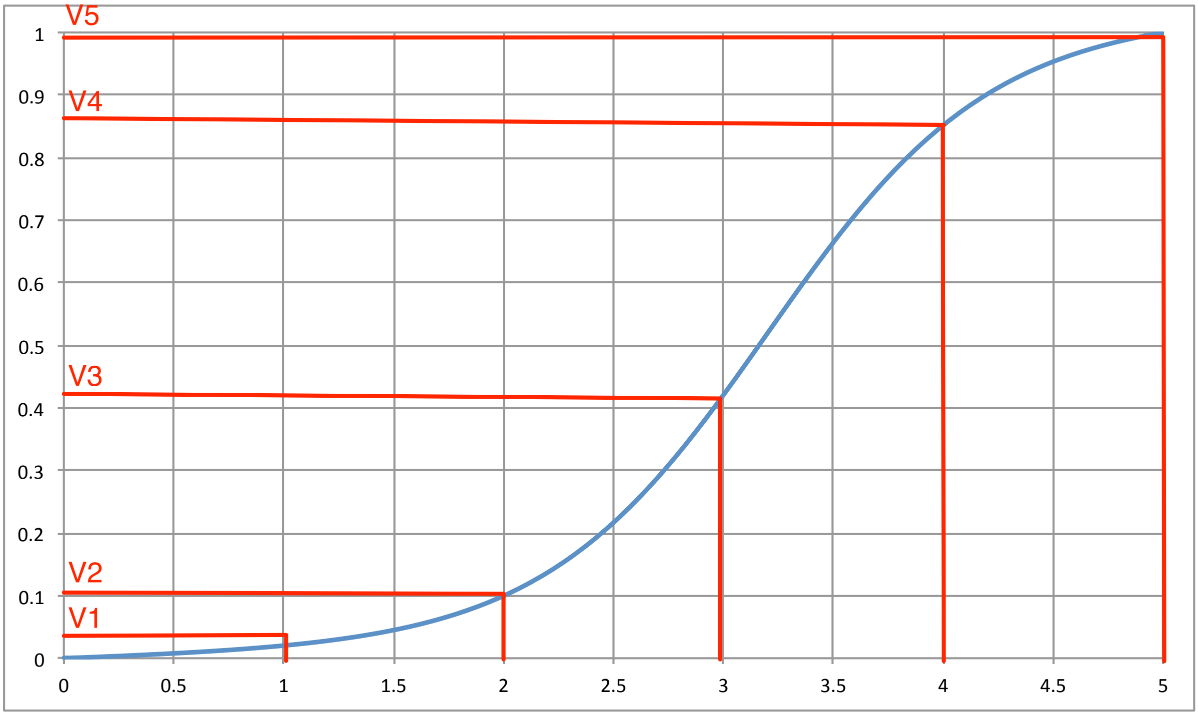

Figure 12: Generic Fragility curve. x-axis: Threat intensity; y-axis: vulnerability or probability of damage.

In the case of heavy rainfall, the best fit of data in Figure 11 with the parametric expression of eq.(5) provides the following values for the 4 parameters: α=1.5 10^{-3} (mm rain)$^{-1}$, β=83 (mm rain), δ=γ=0.4156.

From the curve of eq.6 we could identify five levels of vulnerability (v_i values in Figure 12) associated to five threat levels (i.e., 1, 2, 3, 4, 5) corresponding to five physical quantities T1, T2, T3, T4, T5 (stored in the **Threat Level** table see 3.4.6) in order to associate each threat to a severity level.

3.3.2 Heat waves

Analogously to heavy rainfalls, we analysed the propensity of an electrical substation to be faulted in a hot day. This provides a vulnerability index of a specific electrical substation. By considering the historical log file of faults of CI elements and correlating their faults to climatological data, we have found correlation between frequency of faults and external temperatures (considered as day-peak-temperature or T_{max}). The V_1 index has indicated the presence of electrical stations which have a large propensity to fault during days with maximal daily temperature exceeded T>30°C (Figure 13).

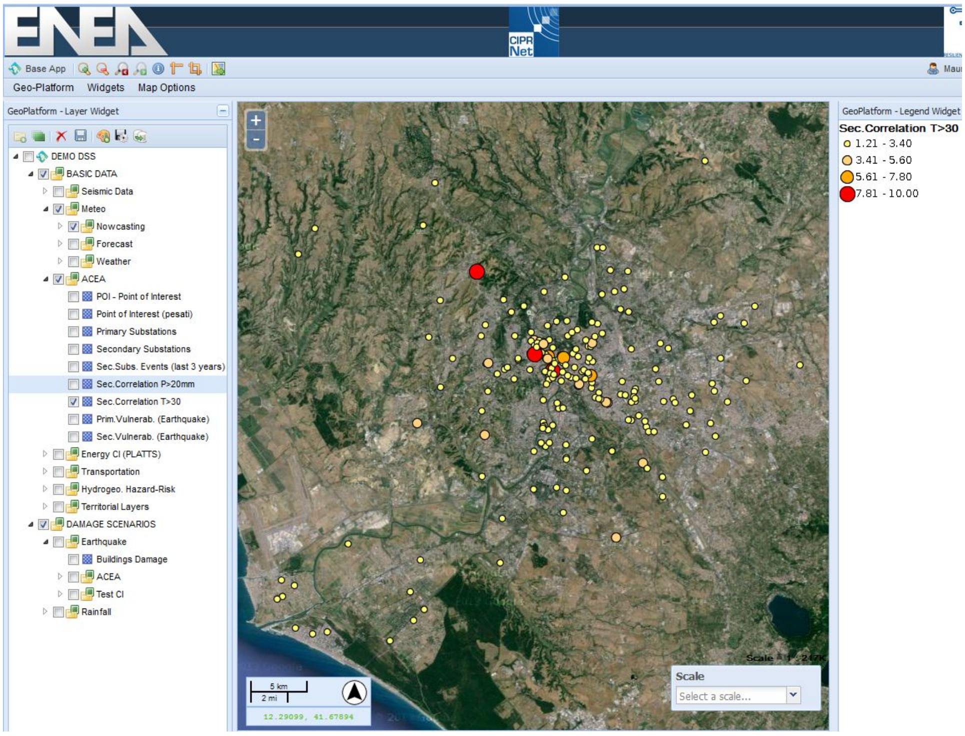

Figure 13: Electrical substations vulnerable to temperature > 30 Celsius grades.

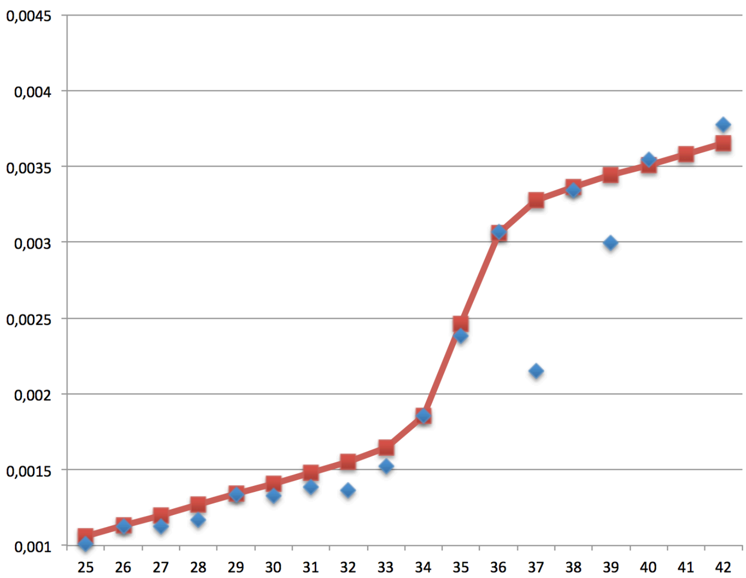

Figure 14: Temperatures (abscissa) versus disconnection probability of electrical secondary cabin (statistics taken over 4 years of measurements).

If the same type of V_2 distribution analysis is made for hot wave, we found a similar (two regimes) distribution curve such as that related to abundant rainfalls, indicating the good validity of the two regimes approximation for these events. In this case we have a linear perturbation regime up to $T_{max}<35$ followed by an abrupt rise of the fault probability (Figure 14) his analysis could be activated to correlate faults with heat or cold waves.

Also in the case of heat waves, the linear-sigmoidal curve seems to better represent the systems behaviour. Best fit of Equation 6: Generic Fault Probability equation., in this case, is achieved by using the following parameters: $\alpha=10^{-5}$ $(°C)^{-1}$, $\beta=35$ (°C), $\delta=\gamma=7\ 10^{-5}$.

3.3.3 Cold waves

Considering that the climate of Rome is mild, we have not found any significant correlation of failures to cold waves. If, in fact, cold waves could be defined as days with T_{min}<-5°C, we have not found any historical data of such event in the area of the city of Roma. We will attempt to perform a similar analysis as described in the two previous sections in (cold) areas where a significant statistics enabling the estimate of a vulnerability function of CI elements with respect to low and very low temperatures.

3.3.4 Earthquakes (b2 method)

In seismic risk assessment, vulnerability functions express the likelihood that assets at risk (e.g. buildings, people) will sustain varying degrees of loss over a range of earthquake ground motion intensities. These functions can be obtained from past earthquake observations, analytical or numerical studies, expert judgement, or a combination of these [10].

The first information available immediately after a significant earthquake consists of the seismic event magnitude and the epicentre. Through spatial analysis, geo-processing and visualisation tools, this information together with spatial parameters such as rock and soil conditions of the affected area, distance from the epicentre and variations in the propagation of seismic waves can be processed for producing ground shaking maps (*Shake Maps*). By overlaying Shake Maps with inventories of critical facilities, transportation network and vulnerable structures it is possible to assess potential damage scenarios: where impacts of the occurred seismic event can be greatest, where structure and infrastructure have likely been damaged, etc.

In order to quantify the effects of local soil conditions on the earthquake ground motion amplification, empirical multiplication factors are generally used. So, a selected ground motion parameter such as Peak Ground Acceleration (PGA) at the bedrock level is multiplied by an empirically derived factor. A commonly used approach to micro-zonation is to determine empirical site-amplification factors for a large set of sites by regression analysis of earthquake data, correlating them to different geotechnical parameters of the site. Several multiplication factors have been identified for different regional areas based on statistical analysis of observed strong ground motion data. These factors are derived by input PGA values by bedrock depth and average shear wave velocity of the soil deposit. The used geospatial methodology and tools are able to produce PGA maps, vulnerability maps and expected damage scenarios.

In order to estimate the surface ground shaking in the interest area and calculate the PGA value, the propagation relationship proposed by Akkar and Bommer [11] is used. For low magnitude events (Mag<4):

$$log_{10}(PGA) = A + B \cdot (Mag - 6) + C \cdot log_{10}[sqrt(R\_epi^2 + H^2)]$$

Equation 7: PGA relationship for M<4 seismic events

where:

A	B	C	H	SIGMA
4.037	0.572	-1.757	6.0	0.3667

For high magnitude events (Mag≥4), Akkar and Bommer [11] propose the following relationship:

$$log_{10}(pga) = b_1 + b_2 \cdot Mag + b3 \cdot Mag^2 + (b_4 + b_5 \cdot Mag) \cdot log_{10}[sqrt(R\_epi^2 + b_6^2)]$$

Equation 8: PGA relationship for M>=4 seismic events

where:

$$sigma\_log10(pga) = sqrt[(s1 + s1m \cdot Mag)2 + (s2 + s2m \cdot Mag)2]$$

Equation 9: PGA propagation relationships [11].

and:

b_1	b_2	b_3	b_4	b_5	b_6	s_1	s_{1m}	s_2	s_{2m}
1.647	*0.767*	*-0.074*	*-3.162*	*0.321*	*7.682*	*0.557*	*-0.049*	*0.189*	*-0.017*

The seismic vulnerability is expressed in terms of macro seismic intensity (I_{MCS}). In particular, PGA and I_{MCS} values are correlated by using the following relation, defined by Decanini et al. [12]:

$$log\ PGA = 0.594 + 0.197\ I_{MCS}$$

Equation 10: relationship between PGA and I_{MCS} [12].

The PGA map of seismic propagation obtained through the Akkar and Bommer [11] approach is automatically produced when an earthquake event occurs (gathering the proper information from INGV ISIDe service[1]) and stored as specific GIS layer into the DSS DB. Subsequently, expected damage maps can be dynamically generated, immediately following an earthquake, by using the described methodology, and likewise stored into the DSS DB as “Damage Scenario” data and maps.

3.3.4.1 Earthquake damages to electrical distribution station

In general, earthquakes could damage all types of power system equipment causing interruptions that may last some days. To this aim, usually, in power distribution station buildings, reinforced concrete, fire- and explosion-resistant walls or barriers, are installed between major pieces of equipment, such as transformers, circuit breakers, and regulators.

Considering seismic events with different severity i.e., PGA values that affect a substation building, it is possible to estimate the vulnerability of a power distribution station based on the structural properties of the building. To evaluate the seismic vulnerability of structures, the detailed buildings inventory of the area of interest has been exploited (source: ISTAT Census dataset), taking into account aggregated data related to: structural typology (masonry or reinforced concrete); age of construction; number of storeys. The **seismic vulnerability index I_v** (ranging from -6 to 60) for each census section has been calculated by using the Lagomarsino and Giovinazzi [13] approach.

To evaluate the seismic vulnerability of CI elements, a detailed inventory is needed (by exploiting information provided by CI Operators). The I_v index for each element considered (e.g. primary and secondary electrical substations) has been derived from the I_v value of the building in which the element itself is located. Such I_v value is suitably reduced, taking into account the intrinsic characteristics of the element considered (for example, an electrical sub-

[1] ISIDe - Italian Seismological Instrumental and Parametric Data-Base by INGV: http://iside.rm.ingv.it/iside/standard/index.jsp?lang=en

station located under a trapdoor, situated at ground level, is characterised by a very low I_v value).

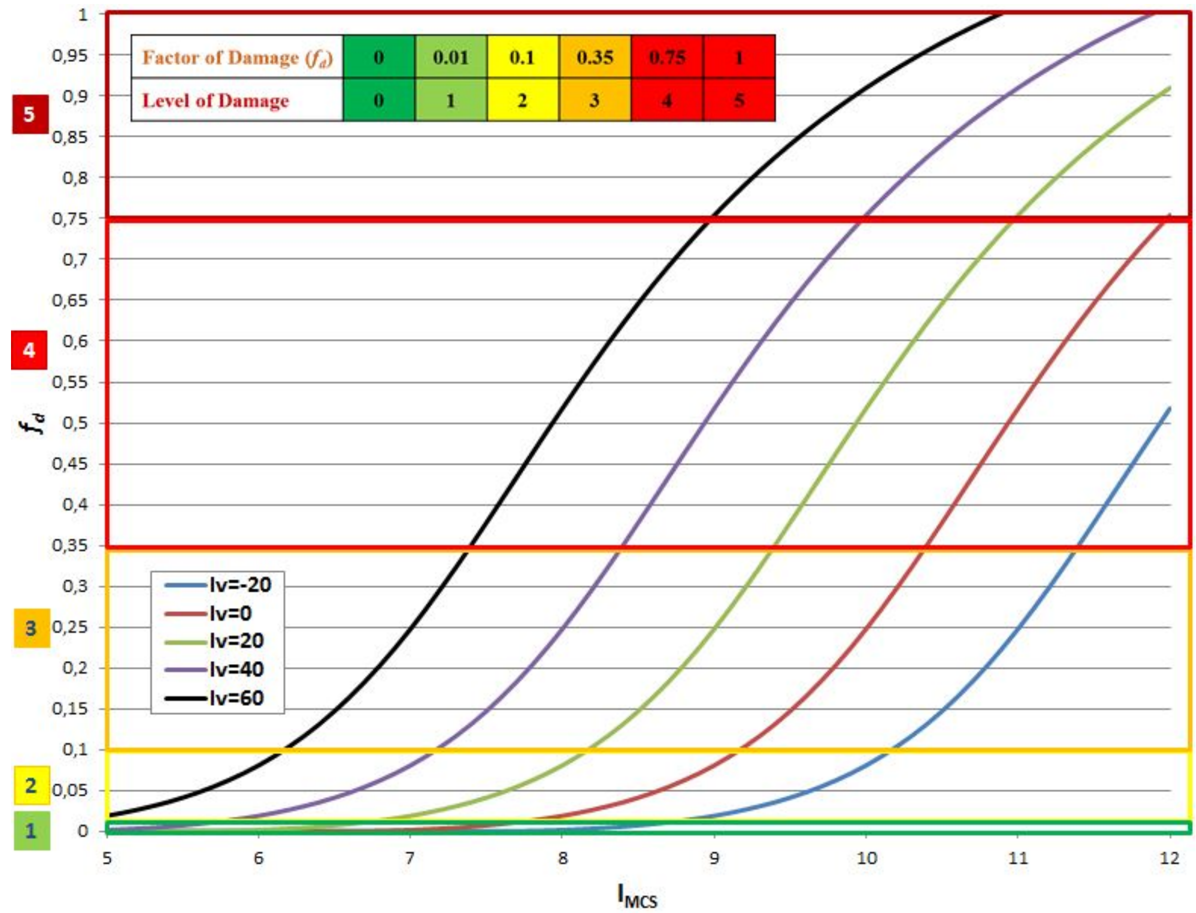

Figure 15: Fragility curves and vulnerability index IV: relationship expressed in terms of mean damage [12].

Then, let us consider following relation:

$$d = 0.5 + 0.45(arctan (0.55 (I_{MCS} - 10.2 + 0.05 I_v))$$

Equation 11: Mean damage and factor of damage for a seismic event [13].

defined in [13], that relate I_{MCS} and I_v to the mean damage d for the building (ranging from 0 to 1), according to the trend of fragility curves depicted in Figure 15.Then, the damage can be expressed by an a-dimensional parameter f_d (ranging between 0 and 1), in order to consequently obtain a correspondence between the levels of damage and the values of f_d calculated by the following equation:

$$f_d = d^{1.75}$$

Equation 12: Factor of damage for a seismic event [13].

To summarise, based on these relations and the I_{MCS} and I_v values calculated, it is possible to calculate the level of damage that can affect each electrical substation to a specific seismic event (real or simulated).

3.3.4.2 Earthquake damages to Base Transceiver Station

A Base Transceiver Station (BTS) is a piece of equipment that allows wireless communication between user equipment (UE) and a network. Today, a large number of BTS antennae is installed in the cities, and they are often located on the roof of buildings. This makes such systems being vulnerable to earthquakes, since a damage on a building where a BTS is installed, may generate disruptions on the Telecommunication system causing the lack of communication for the users in the area covered by that BTS.

With this in mind, we can model the vulnerability of BTS to seismic events based on the structural properties of the building where such components are installed. For example, following the approach described in the previous Section, we consider a building with the same structural properties except for the number of storeys that we assume to be five (to be consistent with common installations of BTS antennae). These properties can be associated to a seismic vulnerability index I_v=20. Following this approach, it is possible to design vulnerability functions that relate the severity of seismic events with the probability of fault of the BTS.

3.3.5 Lightning

Concerning Lightning, the Italian DSS instance will host a system for predicting the probability of lightning in a specific area up to 45 minutes for the current time. Data (Figure 16) will be released by Himet Srl, partner of project RoMA. The company has agreed to provide data to project CIPRNet for testing vulnerability analysis. In general, each DSS instance will "plug" into the DSS workflows the available data sources for the different natural hazards forecast. For example, a specific DSS instance may use public and/or commercial data (e.g. form satellite networks provider) for the prediction of different natural hazards.

Effective stress imposed by lightning on specific CI elements will be reconstructed on the bases of the specific element and by technical datasheet. However, in a first formulation of the vulnerability index of CI elements, all elements presenting telecommunication or electrical attributes will be put in a fault state, unless otherwise specified (for instance for all CI elements which do not have electromagnetic apparatuses).

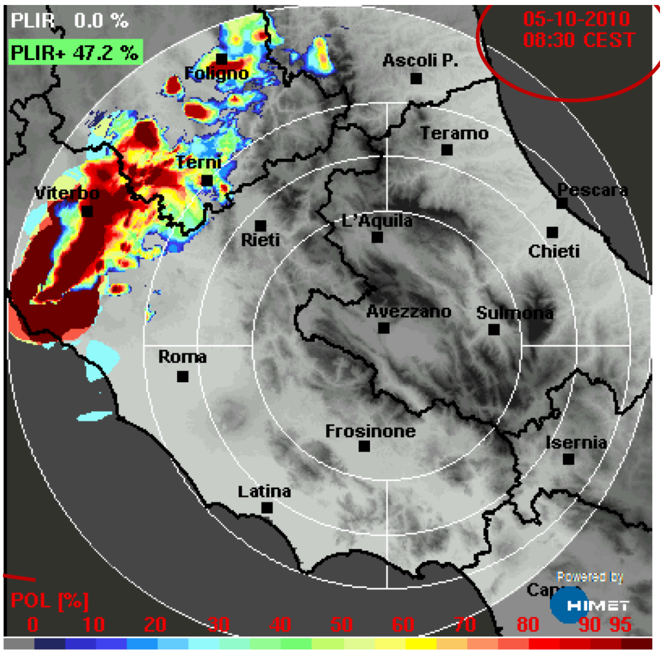

Figure 16: Lightning probability at current time (PLIR) and after 45 minutes (PLIR+).

3.4 Vulnerability Conceptual Schema

In this section we briefly describe the database tables conceptual schema that has been defined to store infrastructure data and information related to their vulnerability w.r.t. the different natural events.

3.4.1 Entity: Infrastructure

Entity name	Entity description
Infrastructure	It stores the set of the considered infrastructures (e.g., Electrical distribution network.

Attributes	Comment
ID *	A unique identifier
name	Name of the infrastructure (e.g., electrical distribution grid)
company	Company name of the Infrastructure operator (e.g. Acea, Siemens)

3.4.2 Entity: Component

Entity name	Entity description
Component	It stores all the physical components of the considered infrastructures (e.g., an electrical line located in a specific place), a geo-reference i.e., the geographical position of the component, and a state i.e., the probability of physical damage that is estimated according to Equation 4.

Attributes	Comment
ID *	A unique identifier
name	Name of the component (e.g., a secondary distribution station, an electrical backbone)
georeference	Georeference properties of the CI component
state	1 if considered functioning, 0 if considered in fault

3.4.3 Entity: Component-Type

Entity name	Entity description
Component-Type	It stores the type of each physical component (e.g., a Medium Voltage electrical substation, an electrical line).

Attributes	Comment
ID *	A unique identifier
type	Type of CI component
description	Description of the type of component

3.4.4 Entity: Vulnerability

Entity name	Entity description
Vulnerability	It stores, for each physical component and natural threat, the five thresholds that define the physical vulnerability containing 5 levels (from 1 to 5) as defined in Equation 3.

Attributes	Comment
ID *	A unique identifier
V1, V2, V3, V4, V5	Physical quantities indicating vulnerability thresholds

3.4.5 Entity: Threat

Entity name	Entity description
Threat	It stores all the natural threats that the DSS is able to detect. Each threat is identified by a name, the time at which the threat is detected or predicted and the unity of measure (e.g., mm of water for rainfalls) that is used to quantify the intensity of the threat.

Attributes	Comment
ID *	A unique identifier
time	The time at which a natural hazard is acquired and stored
Name	Name of the threat (e.g., an earthquake)
Unit_of_measure	The unit of measure that is used to quantify the natural threat

3.4.6 Entity: Threat-Level

Entity name	Entity description
Threat-Level	It stores, for a given threat, the intensity containing 5 levels (from 1 to 5) as defined in Equation 2 specified according to the unity of measure in the Threat table. For example for an earthquake, we define five different PGA values to describe the intensity of the threat.

Attributes	Comment
T1, T2, T3, T4, T5	Physical quantities indicating threat thresholds that are used to quantify the severity of the natural threats.

3.4.7 Entity: Event

Entity name	Entity description
Event	It stores the outcome of the forecast model relative to the different natural threats predicted for the short and long term according to the unity of measure in the Threat table. For example, it can store a severity of a rainfall specified as 15 mm of water in two hours (short term).

Attributes	Comment
Short_term	Estimation of threat severity in the short term (less than 1 hour)
Long_term	Estimation of threat severity in the long term (> than 1 hour)

The content of the Component table and the Event relation are continuously updated by the DSS to store the last events occurred to perform the B_4 analysis. In particular, when an incident is detected, the DSS uses the data stored in the presented data structures to implement the process described in Section 3.1 to estimate the probability of physical damage that is estimated according to Equation 4 i.e., the state field stored in the Component table. If such probability is over a specified threshold (that will be set through DSS validation phases), the component is considered to be damaged and will be part of the PHS.

3.5 Impact Conceptual Schema

In this Section we present how the information relative to the existing (inter)dependencies are stored in the DB. We also show how we produce an outcome of the impact assessment module performed in B_4 and how we store this information in the DB.

The dependency links, interconnecting CI in a system where many CI are present, configure a System of Systems where, in principle, the fate of one infrastructure is dependent from the fate of the others. Again, in principle, the strength of the interaction link connecting one CI to another defines the level of dependency: stronger the link, higher the dependency, faster the repercussion of a perturbation from the one to the other. Similarly to a "condensed matter state" (whose analogy is going to be exploited for this metaphor) the strengths of the dependency links among the different CI (seen as different interacting bodies) determine the velocity and the "characteristic" times of the dependency (cascading) effects, that is the time needed to see a perturbation propagating from one system to the other.

In the realm of CI systems, we could (arbitrarily but on the basis of some phenomenological data) identify electrical and telecommunication CI as those presenting the strongest dependency links: after all, telecommunication provides the vital tele-control functionality to electrical networks whose functionality would be unstable without fast tele-control operation. Thus we will assume that electrical and telecommunication CI could be treated separately with respect to the other infrastructures in a sort of "adiabatic" approximation: the DSS will first resolve the dependency mechanisms among these two CI and then, after having solved the fault propagation and established the service unavailability of these two systems, propagate to the other CI the effects of their unavailability.

In particular, we will focus on the short time scale impacts assessment. Starting from the predicted damages in a test case involving a distribution power network and the relative SCADA system, the impact assessment module computes the reduction of QoS of the electrical network due to the predicted damage scenario. In general, the impact assessment module is composed of two different phases: in the first, strongly coupled infrastructures (such as the electrical and the telecommunication ones) are considered. Their strong coupling activates dependency mechanisms holding in the short time scale (from a few minutes up to one hour). Coupling of these infrastructures to other CI establishes with a larger latency: during very short times scales, other CI could be considered as "decoupled" from the previously cited infrastructures, in a sort of adiabatic approximation. In the following the first phases will be described in detail. Regarding the second phase, the DSS will integrate interdependencies simulator ([21]) to consider within the impact assessment generic and long time scale interdependency phenomena.

3.5.1 Power grid and SCADA system

Considering that our vulnerability analysis has focused on the electrical distribution grid of Rome and its relative Telecom/SCADA network, we model some high-level components of such networks. In particular, we consider the electrical grid consisting of a set of High Voltage (HV) Primary Substations (PS) and Medium Voltage (MV) Secondary Substations (SS).

Each PS may have one or more backbones that are connected to other PS. The SS are connected in a series configurations and each backbone contains two semi backbones that are divided by a normally open switch that can be closed in order to implement reconfigurations operations. SS that are equipped with remote control functionality can be managed by the SCADA control centre serving the electrical distribution network to implement recovery operations (e.g., to isolate a SS). Instead, SS with no remote control functionality cannot be operated remotely and the electric provider should send crewmen in order to operate on the SS. The remote control functionality serving specific SS is provided by a Base Transceiver Station (BTS) installed in an antenna that is located in the proximity of a set of SS that is part of a the Telecommunication network.

3.5.2 Entity: PrimarySubstation (PS)

Entity name	Entity description
PS	Containing the set of primary substations ID;

Attributes	Comment
ID *	A unique identifier

3.5.3 Entity: Semibackbone (SB)

Entity name	Entity description
SB	Containing with the set of the semi backbones ID associated to each primary substation;

Attributes	Comment
ID *	A unique identifier
ps	The primary substation that is connected to the considered semi-backbone

3.5.4 Entity: Backbone

Entity name	Entity description
Backbone	Containing the set of couples of semi backbones ID that constitute a backbone;

3.5.5 Entity: BTS

Entity name	Entity description
BTS	Containing with the set of the ID of the BTS that provide the telecommunication service in a certain area;

Attributes	Comment
ID *	A unique identifier

3.5.6 SecondarySubstation (SS)

Entity name	Entity description
SS	Contains the set of secondary substations ID, the relative semi backbone ID, a flag indicating the presence of the remote control, the position occupied in the semi backbone, the number of electric users energised by that substation in normal conditions.

Attributes	Comment
ID *	To improve interoperability, ID is the one provided by the operator. Example CS004537 for a secondary cabin of ACEA distribution grid
sb	The semi-backbone connected to the considered secondary substation
order	The order where the considered secondary substation is located on the semi-backbone
Open_switch	1 if the substation is connected to a normally open switch
Remote_control	1 if the substation is connected to a normally open switch
users	Number of electric consumers served by the substation

3.5.7 Entity: ElectricConsumer

Entity name	Entity description
ElectricConsumer	is the set of ID denoting the electric consumers (e.g., hospitals, residents, governmental buildings) together with the indication of the ID of the SS that supply them;

Attributes	Comment
ID *	A unique identifier

ss	The ID of the secondary substation that normally feeds that user

3.5.8 Entity: ProvideTelco

Entity name	Entity description
ProvideTelco	Relates the ID of each BTS with the set of ID of secondary substations that receive communication from that BTS;

3.5.9 Entity: ProvideEnergy

Entity name	Entity description
ProvideEnergy	Relates the ID of each remotely controlled secondary substation with the ID of the BTS that is supplied by that substation. The ProvideEnergy table models all the dependencies among the power network and its electrical consumers i.e., the BTS and the hospitals whereas the ProvideTelco table models the dependencies among the power network and the Telecommunication network that enables the SCADA communication to the remote controlled SS.

4 Consequence Analysis

This section describes the technical concepts and realisation of our Consequence Analysis approach. A more detailed embedding into related work will be provided in a forthcoming scientific publication.

In this new methodology a distinction will be made between the *CI related Consequences* (i.e. the consequences of CI reduction and/or loss of their QoS) as opposed to the *No-CI related Consequences* that are the consequences related to the primary effects of a severe natural event (e.g. an earthquake).

The DSS will firstly provide a forecast (or, in case of occurred events, an assessment) of ALL the Damages produced by the events, according to the data availability in the DB.

The system will thus distinguish between No-CI related damages (i.e. those which will be produced on people and assets which are not related to CI or CI-related objects, whose damage can, in some way, produce some repercussion on CI functioning). These damages are local and produce local Consequences (casualties, asset disruption etc.) whose Consequences can be directly estimated. CI-related damages (and, thus CI-related Consequences) are in turn those affecting CI elements and which might have a repercussion (Impact) on the CI functioning and in their capability of providing the expected Services. These damages are at the centre of the DSS interest as they can produce local and non-local Consequences, due to the "amplification" behaviour that the system of CI can produce through cascading effects (which can spread in space and time the perturbation originally localized into the damages of the CI elements)

The main objective of this section is the description of the proposed methodology for the assessment of CI related Consequences and how this new methodology can integrate, in case of large crisis, the Civil Protection No-CI related Consequences Analysis.

Then, the proposed methodology will contribute to solve the prediction of which Consequences will be related to Impacts (i.e. reduction or loss of Services provided by CI) once one (or more) CI elements are damaged by threats manifestations.

The model introduces the concept of "Consequences" of a Critical Scenario in terms of "societal" wealth reduction, associated to the expected Impacts on CI-supplied Services, under different viewpoints that will be called ***Criteria***. The proposed model is particularly useful when associated to a risk analysis workflow. In fact, after the prediction of specific Damages (resulting from natural or other types of threats) and the estimate of the related Impacts on CI functioning, the resulting outages (called Services Unavailability) can feed a Consequences Analysis model which, through the use of specific Service Availability Wealth Indices (called SAWI) allows to "weight" the Crisis Scenario.

In general, we could introduce the meaning of consequences of the related impacts on CI of a damage scenario as being the reduction or loss of well-being, which results (comes after) from the impacts and can be estimated according to some specific metrics.

This definition has the property of reconnecting an abstract and generic term (Consequences) with the realm of measurable quantities, although related to different (and diverse) fields. In fact, "affected well-being" could be related to different fields of the daily life and concern with the intrinsic well-being of citizens (their "wealth"), with the integrity of their own assets, with the wealth and the integrity of the environment (which could be damaged in terms of pollution, disruption and/or devitalisation of specific areas), with the reduction of functionality of Primary Services that would, in turn, affect the well-being of citizens, with the reduction of "wealth" of the different economic sectors which are directly or indirectly wounded by the Damages.

According to our definitions, Consequences Analysis (CA hereafter) will thus encompass the study of all the reductions (or losses) of well-being in many different domains and under different viewpoints or ***Criteria***.

Before we address the definition of the different "wealth indices" required to perform CA, the main term specifications are recalled.

- By **No-CI related Consequences (**No-CI Consequences in the following**)** we indicate those consequences related to *primary effects* of the Damages (the number and the economic value of a collapsed building, the number of casualties produced by a specific event, the economic losses related to the disruption of a given production plant etc.).
- By **CI related Consequences** we indicate, in turn, those consequences related to the functionality losses in the Critical Infrastructures-provided Services (electricity, water, gas, transportation means etc).

It is worthwhile to note that, in general, No-CI Consequences are limited to the area affected by the natural events. On the contrary, the area to which CI related Consequences refer to can be much larger than the affected area. The CI related Consequences spreading effect is mainly due to CI outages cascading effects.

A typical example of this situation is the 2003 Italian blackouts where the large *CI related* Consequences (caused by an extended and prolonged electrical blackout) have been triggered by a Damage that produced very small *No-CI* Consequences (i.e. the collapse of an high tension pylon). This is often the case when (inter)dependent infrastructures are involved. (Inter)dependency mechanisms often introduce in the cause-effects relations, large non-linear behaviour which are then able to produce dramatic cascading effects and Consequences amplification.

Whether *No-CI* Consequences can be evaluated on the basis of the produced Damages, the transformation of Damages into *CI related Consequences* is more complex and requires the introduction of a further term, which we will indicate as **Impacts**. These are the resulting effects of Damages on the Services produced by Critical Infrastructures. As an example, the Impact on the electrical distribution caused by the Damage to a Secondary substation for medium-low tension transformation is the electrical outage in a specific city area for a given period of time and the related (through (inter)dependency effects) outage of telecommunication system (which, for instance, could not be supplied anymore by electrical power).

The workflow for relating Damages to their indirect Consequences will thus pass through the estimate of all Impacts (in terms of reduction or loss of Services) of all the (inter)dependent Infrastructures, not only the wounded one(s). Once having the complete assessment of the Impacts, with technique similar to those used for the *No-CI* Consequences, one can evaluate the *CI related Consequences* by transforming Impacts in well-being variation, according to the same ***Criteria*** valid for *No-CI* Consequences estimates.

Consequence Analysis, in the CIPRNet acceptation, will mainly focus on CI related Consequences for, at least, two reasons: the first, being No-CI Consequences evaluated and predicted by Civil Protection and the second due to the fact that a Competence Centre for Risk Analysis of Critical Infrastructures will be supposed to be the only Centre having information allowing coherent and complete analysis of Consequences deriving from Services Losses. This does not mean that the CIPRNet DSS will not attempt to provide estimates for No-CI Consequences, which will be provided to Public Authorities, in the limits of the data availability in the DSS DB; it only means that our efforts should be primarily devoted to estimate CI related Consequences that are not predicted anywhere else.

With respect to the No-CI Consequences, our GIS tool and the availability of a number of information layers in the DB, will allow the DSS to evaluate:

- Damages to buildings and estimated related casualties
- Damages to industrial plants and estimated related casualties
- Damages to roads, railways and estimated related losses in mobility
- Damages to industrial plants and estimated related GDP losses
- Expected flooded areas and number of involved citizens
- Flooded areas and estimated related GDP losses

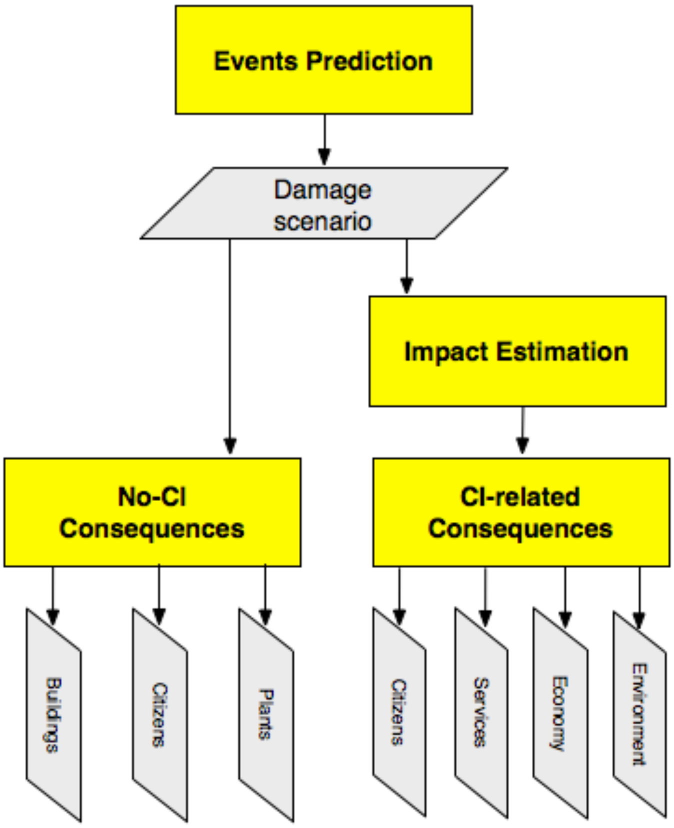

Figure 17: Outcomes of the evaluation performed through No-CI and CI related approaches.

The methodological framework for No-CI Consequences will be described in detail in an further CIPRNet document ([22]), together with a review of the available scientific documents on the different existing approaches dealing with No-CI Consequences evaluation. In this Section we present our approach on CI related Consequences. Before going into details of the two approaches, we introduce the Consequence Analysis Criteria that define those aspects of societal life that our DSS evaluates based on a specific impact scenario.

4.1 Consequences Analysis Criteria

The European Council Directive 2008/114/EC [15] defines that the significance of the impact produced by the disruption or destruction of a European Critical Infrastructure (ECI) shall be assessed in terms of cross-cutting *criteria*. These include effects resulting from cross-sector dependencies on other types of infrastructure and should comprise the following:

- ✓ **Casualties criterion** (assessed in terms of the potential number of fatalities or injuries);

- ✓ **economic effects criterion** (assessed in terms of the significance of economic loss and/or degradation of products or services; including potential environmental effects);
- ✓ **public effects criterion** (assessed in terms of the impact on public confidence, physical suffering and disruption of daily life; including the loss of essential services.

The cross-cutting criteria thresholds shall be based on the severity of the impact of the disruption or destruction of a particular infrastructure and will be determined on a case-by-case basis by the Member States concerned by a particular critical infrastructure.

We have tried to summarise, in a unique list of ***Criteria***, a number of domains that "expresses" the cross-cutting Criteria above mentioned, whose well-being reduction could be estimated as in the No-CI and in the CI Consequence analysis. These Criteria will be called ***CA Criteria*** and hereby referred to as t_{ij} where *i* is the CA criterion index and *j* is its component.

Criterion 1 relates to population, to citizens and encompasses the reduction of well-being to the most vulnerable population layers.

CA Criterion 1: Citizens

- t_{11} = old age people;
- t_{12} = children;
- t_{13} = disabled;
- t_{14} = average population;

Criterion 2 relates to the Primary Services that affect the wealth and the well-being of the population. These might be ascribed to "public effects" criterion as they focus on assets/services that might be also of vital relevance (such as Hospitals) for citizens.

CA Criterion 2: Services

- t_{21} = Hospitals;
- t_{22} = Schools;
- t_{23} = Public Offices;
- t_{24} = Public Transportations;

Criterion 3 relates with the economic losses that depend, in turn, on the integrity and the lack of production hours/days due to Services outages. Segmentation has been done by using the industrial sectors (primary, secondary, tertiary) as this ontology is used to group available data.

CA Criterion 3: Economy

- t_{31} = Primary (agriculture, farmland);
- t_{32} = Secondary (manufacturing);
- t_{33} = Tertiary (services);

Criterion 4 relates to the environmental damages. Environment can be directly hit by disruptions (landslides, flooding etc.) but also by secondary effects (pollution, leakage from plants and other disrupted industrial sites, etc.)

CA Criterion 4: Environment

- t_{41} = Forests;
- t_{42} = Protected areas (Natural Parks etc.);
- t_{43} = Sea and shores;
- t_{44} = Natural and artificial basins.

The CA module of the CIPRNet DSS will thus provide an estimate of the No-CI and of CI related Consequences performed according to the previously defined ***Criteria***.

In the Table 3, we attempt to classify the quantitative terms that will be behind the specific Criteria. Example: the No-CI Consequences related to the t_{21} criterion (i.e. Public Services/Hospitals) will be the count of the number (#) of Hospitals effectively affected by physical damages. The CI related Consequences would, in turn, identify the reduction of its functionalities (expressed, for instance, in terms of patients healed per hour) due to primary Damages and lack of CI-related services. In the following Table 3 we report the "metrics" used for measuring the Consequences of the specific Criteria.

Table 3: List of metrics for the considered Criteria.

	No-CI related Consequences	**CI related Consequences**
Criterion 1	t_{11} = # casualties	t_{11} = # affected by services unavailability
	t_{12} = # casualties	t_{12} = # affected by services unavailability
	t_{13} = # casualties	t_{13} = # affected by services unavailability
	t_{14} = # casualties	t_{14} = # affected by services unavailability
Criterion 2	t_{21} = # disrupted	t_{21} = reduction of functionality
	t_{22} = # disrupted	t_{22} = # closed due to lack of services
	t_{23} = # disrupted	t_{23} = # closed due to lack of services
	t_{24} = # disrupted	t_{24} = # not available due to lack of services
Criterion 3	t_{31} = # disrupted	t_{31} = value of the economic losses due to services unavailability
	t_{32} = # disrupted	t_{32} = value of the economic losses due to services unavailability
	t_{33} = # disrupted	t_{33} = value of the economic losses due to services unavailability
Criterion 4	t_{41} = # disrupted	t_{41} = surface affected by disruption-related events
	t_{42} = # disrupted	t_{42} = surface affected by disruption-related events
	t_{43} = # disrupted	t_{43} = surface affected by disruption-related events
	t_{44} = # disrupted	t_{44} = surface affected by disruption-related events

In the following, the CI related Consequences assessment methodology will be described in detail. As previously explained, their estimate is much more complex that the estimate of no-CI related Consequences; their identification has required the design of a "novel theory" which, starting from existing metrics for wealth estimate, has allowed to define how a Services outage (i.e. the Impact consequent to a CI related damage) could imply Consequences and how to measure them. This will be the object of the next Section 4.2

4.2 CI related Consequences

In the CIPRNet DSS workflow the CI related Consequences analysis will be performed within the DSS B_4 block that among the others, it will contain specific software components able to perform the Impacts assessment, the Consequence Analysis and, in some cases, also suggest optimal strategies of mitigation crisis to decision makers.

Figure 18 shows a flowchart representing the different software components that realise the DSS B_4 functionality. The diagram shows the Consequences Analysis module (CAm) that is able to estimate the ultimate effects that the reduction (or loss) of Primary Technological and Energy Services produce on relevant sectors of daily life.

As Primary Technological and Energy Services we consider:

- ✓ **Electricity**
- ✓ **Telecommunications (voice, IP etc.)**
- ✓ **Water (drinking water, waste water management)**
- ✓ **Gas and other energetic products**
- ✓ **Mobility (roads, railways)**

We have selected these Services as these are those which, more than others, influence the well-being of the population, condition the availability of primary services such as hospitals and schools, and are responsible for the functioning (or the stop) of industrial plants etc.

The CAm will thus receive a set of impact indicators from the Impact Assessment module (IAm) module and, on the bases of a number of data and simulation tools present in the DSS is able to estimate the consequences deriving from a crisis scenario and, in some cases, to suggest strategies to reduce the consequences through a wise use of available resources.

The CAm is composed of three different subcomponents that are described in the following:

- ✓ **The Consequences estimator**
- ✓ **The Grade estimator**
- ✓ **The Consequences Optimisation procedure**

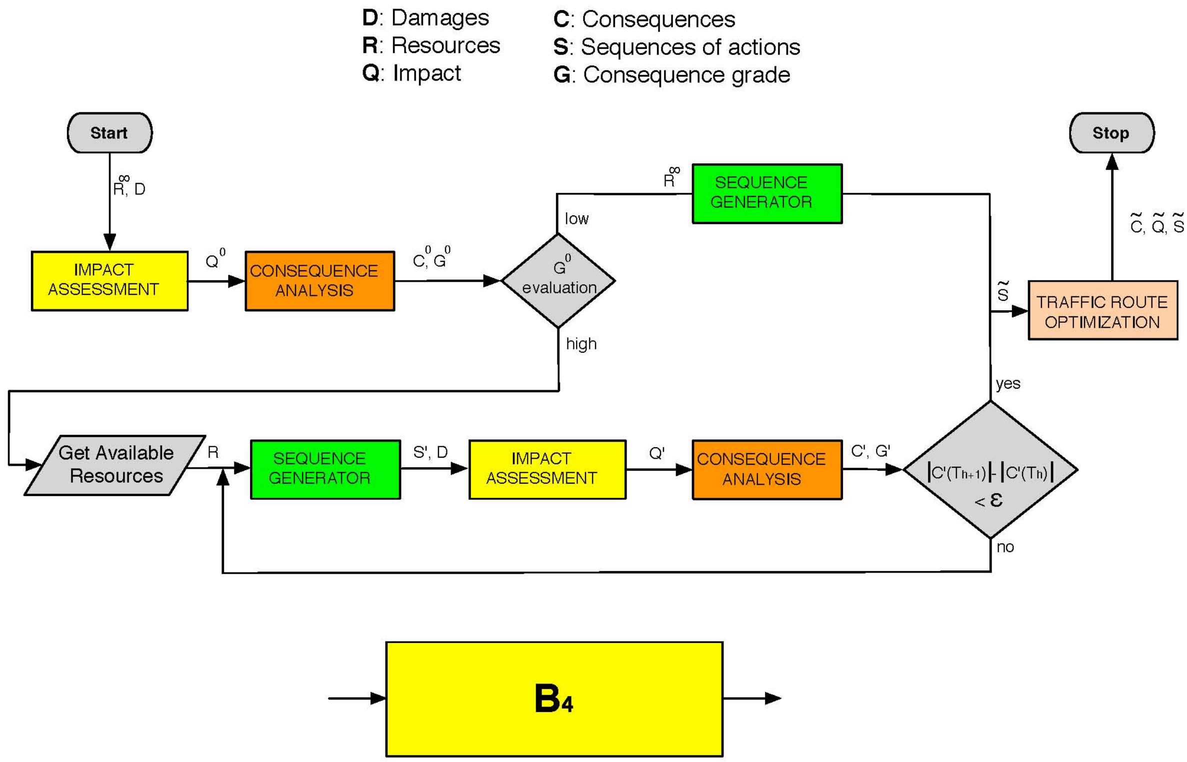

Figure 18: Flowchart representing the DSS B_4 block.

4.2.1 Consequence Estimator

The Consequence Estimator receives data from the Impact Analysis module. Provided data are the **Impact Vector Q** containing the following string of data:

$$\mathbf{Q} = \mathrm{N}, N_{\alpha}, N_{\beta}, , . . , x_{1\alpha}, (t_{1\alpha},), x_{2\alpha}, (t_{2\alpha},), , \dots \dots x_{\mathrm{N}\omega}, (t_{\mathrm{N}\omega},)$$

Equation 13: Impact Vector Q.

where:

- ✓ N is the total number of CI elements in a faulted state
- ✓ N_{α}, N_{β},.., being the number of elements in faulted state in network α,β ..ω respectively (such as $N= N_{\alpha}+N_{\beta}\dots+N_{\omega}$).

It is worth stressing that the **Q** vector is different from the **D** (Damage) vector. If the latter contains the CI elements effectively damaged by the event, the former contains the operability reduction (or loss) of Services that have been reduced not as a direct results of damages of its CI elements but having been affected by dependency phenomena. The time values refer to the predicted initial and final time of the faulted state. Fault periods are defined on the bases of statistical data of elements restoration times provided by the CI operators.

The Consequence estimator, based on the vector **Q** and on the metrics that will be described in the following paragraphs, evaluates the effects of the faulted CI elements on the CA criteria. Before going further, we need to introduce some further concepts and definitions.

4.2.1.1 Wealth indices

Wealth is a general term encompassing a large number of issues e.g., economical, related to societal health and to other domains defining the GPI (Genuine Progress Indicators). In our approach to evaluate the CI related Consequences, we only focus on the definition of a sub-class of ***Wealth Indices***, which are related to the outcomes of the access and the availability to primary and vital technological services (see Section 4.1). The access to these services brings a number of beneficial consequences, which we wish to appropriately measure. With such indicators, we are able to measure the reduction of well-being (Wealth) consequent to Services unavailability.

There is a large and lively debate on the use of specific indices for correctly representing well-being and societal wealth which goes beyond the simple economic indices (e.g., GDP, see the content of a famous Robert Kennedy talk[2]). Influential scientific literature [16] considers a number of low correlations between GDP and suggests the use of other types of

[2] GDP measures everything except that which makes life worthwhile. "*Our Gross National Product ... counts air pollution and cigarette advertising, and ambulances to clear our highways of carnage. It counts special locks for our doors and the jails for the people who break them. It counts the destruction of the redwood and the loss of our natural wonder in chaotic sprawl. It counts napalm and counts nuclear warheads and armored cars for the police to fight the riots in our cities..., and the television programs which glorify violence in order to sell toys to our children. Yet the Gross National Product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything, in short, except that which makes life worthwhile. And it can tell us everything about America except why we are proud that we are Americans*." Robert F. Kennedy, speech at the University of Kansas, March 18, 1968

measures with sample a larger area than the mere economical subsystem. In Costanza et al. work [16] we read:

> "..*By measuring only marketed economic activity (the inner circle), GDP ignores changes in the natural, social, and human components of community capital on which the community relies for continued existence and well-being. As a result, GDP not only fails to measure key aspects of quality of life; in many ways, it encourages activities that are counter to long-term community well-being...*".

In our approach to CA we will attempt to provide an estimate of the reduction of Wealth imposed by the absence of the Services that are at the centre of the observational and risk analysis of our DSS. In this we implicitly admit that these indices are far from being comprehensive Wealth Indices are just the identification of the part of a generalised wealth estimate, which is primarily based on what we call "services availability". This approach is similar to that which introduces the "assets availability" as a metrics for determining the societal well-being known as the **International Wealth Index** IWI [16].

We thus introduce what we could analogously call **SAW** (***Service Access Wealth***) **indices** which allow us to define the associated part of Wealth and are useful to describe its variation with the variation in the accessibility of relevant Services enabled by technological and other (energetic, water etc.) infrastructures.

Before analysing in detail the composition of the different CA Criteria, let us introduce the main quantities that will be evaluated in the CAm. Let us attempt to provide a general formulation of Wealth and Wealth variation and to specialise it for the different CA Criteria Elements t_{ij}, which have been identified.

Let us define the **Wealth $W(t_{ij})$** of a CA Criterion element t_{ij} as a function of the available Services Q_k as follows:

$$W(t, t_{ij}) = M(t_{ij}) \sum_{k=1}^{N_k} r_k(t_{ij}) Q_k(t)$$

Equation 14: Wealth of a CA criterion element.

where:

- N_k is the total number of the considered Services which contribute to Wealth;
- $M(t_{ij})$ is the metrics for Wealth measure (see Table 3). This could be related, for instance, to GDP produced per hour of activity (for an industrial plant or domain), or the number of patients healed in a unit of time for an Hospital or the extent of land which might efficiently be used for some industrial or environmental purpose etc.; it will thus express the issue which would be maximally perturbed in that CA Criterion element by the unavailability of Services.
- $r_k(t_{ij})$ is the ***relevance*** of the k-th Service for the achievement of the maximum level of the Wealth quantity M for a given element of Criteria. It might happen that a specific Service, more than others, enables the achievement of Wealth (e.g., electricity for people depending on biomedical devices, water availability for specific industrial plants) and other being less vulnerable for a lack of it;
- Q_k is the unavailability (if $Q_k = 0$) or, in case of availability, the Quality of Service k. In principle, this function depends explicitly on time and describes the pattern followed by the outage of the k-th Service during the time course of the Crisis.

The set of values indicating $M(t_{ij})$ and $r_k(t_{ij})$ are indicated as **SAW indices**. For each CA Criterion and, within a given CA Criterion for each CA Criterion element t_{ij}, we should evaluate specific SAW indices containing all the required data for estimating $W(t_{ij})$ according to Equation 14.

A normalisation constraint can be introduced for $r_k(t_{ij})$ of a given t_{ij} in a way to set to 100% the sum of all the relevance indices.

Under these assumptions, the CAm evaluates what happens to the different CA Criteria elements t_{ij} if one (or more) Services k will reduce its QoS or if that will completely be lost.
We thus define ***Consequence*** on CA Criterion Element t_{ij} the Wealth variation associated to the variation of the availability of Primary Services (see Table 3).

To evaluate the Consequence ***C*** on the CA Criterion Element t_{ij} (for simplicity, we will drop hereafter the t_{ij} variable) due to the Q_k variations (in time), we will integrate, on the time duration T of the Crisis, the following expression:

$$C = W_0 T - M \int_0^T \sum_{k=1}^{N_k} r_k Q_k(t) dt$$

Equation 15: Consequence *C* on the CA Criterion Element t_{ij}.

where:

- ✓ W_0 would be the total Wealth during time T (without the perturbation, i.e. $W_0 = M$);
- ✓ the second term at the r.h.s. represents the effective Wealth of the CA Criterion Element due to Crisis, i.e., due to the variation in time of the QoS of one (or more) Services k, $Q_k(t)$.

In the approximation that r_k is independent on time, Equation 15 turns into:

$$C = M \left[1 - \sum_{k=1}^{N_k} r_k \int_0^T Q_k(t) dt \right]$$

Equation 16: Consequence *C* on the CA Criterion Element t_{ij} with relevance r_k independent from time.

The C value of Equation 16 should be summed up on all the “individuals” composing the involved CA Criteria elements. In absence of specific values of quantities of elements, the C value could express a *density of Consequences.* The values of $Q_k(t)$ are the results of the Impact Analysis. The r_k coefficients are peculiar for each CA Criterion Element t_{ij} and represent the relevance of that specific Service, for the Wealth fulfilment of that CA Criterion element.

Thus, we can represent the outcome of the Consequence Estimator as a **Consequences vector *C*** containing the results of Consequences estimates in the 4 different CA ***Criteria***:

$$C = \begin{Bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{Bmatrix}$$

Equation 17: Consequence Vector C.

With respect to the extent and the severity of a predicted Crisis Scenario, the ***C*** vector will contain the indications on its severity with respect to the 4 identified CA criteria.

Although this vector spans over 4 different CA criteria, we have identified, for each considered criteria, a number of “independent” elements which can be treated separately such as “old aged people”, “children”, “Disabled” for the CA criteria “Citizens”.

If the Consequences in each of those Sectors elements are evaluated separately, the overall dimension of the C vector will increase. ***The C vector reflects the methods of keeping Criteria's consequences "unmixed" so that we can provide their estimates as they are i.e., without making hypotheses on their possible composition, in order to extract a single final quantity***. This attempt would require, in fact, the introduction of complex weights to transform economical metrics into social metrics, and vice versa. This will not be attempted, as it could have profound ethical implications. The choice of the Consortium is to keep apart the extent of the Consequences predicted in the different Sectors and to provide a clear and unambiguous indication to Decision Makers on the type and extent of the expected Crisis Scenario.

Let us analyse in some details the different CA Criteria and relative elements.

CA Criterion 1: Citizens. Census data allows considering the composition of citizens under different viewpoints (see Annex II). A showed in Table 4, we will focus on the more vulnerable areas of population (e.g., old aged people, children, disabled people) that should be better protected against risks derived by the lack of primary services (e.g., electricity, water, gas). However, we also perform an overall estimate of the amount of population involved.

Table 4: A typical SAW matrix for the 4 different CA Criteria Elements of the Citizens Sector (if the normalisation constraint is adopted).

	Services					
CA Criteria	Electricity	Telecom	Water	Gas	Mobility	Total
Aged people t_{11}	$r_1(t_{11})$	$r_2(t_{11})$	$r_1(t_{11})$	$r_4(t_{11})$	$r_5(t_{11})$	100
Children t_{12}	$r_1(t_{12})$	$r_2(t_{12})$	$r_2(t_{12})$	$r_4(t_{12})$	$r_5(t_{12})$	100
Disabled t_{13}	$r_1(t_{13})$	$r_2(t_{13})$	$r_3(t_{13})$	$r_4(t_{13})$	$r_5(t_{13})$	100
Average citizens t_{14}	$r_1(t_{14})$	$r_2(t_{14})$	$r_3(t_{14})$	$r_4(t_{14})$	$r_5(t_{14})$	100

CA Criterion 2: Services. For Primary Services, we will embrace:

- ✓ Hospitals and First Aid Centres
- ✓ Schools
- ✓ Public Offices
- ✓ Public transportations

The Consequences on these CA Criterion elements due by the loss of the functions granted by CI are evaluated in terms of number of affected structures, their normal daily productivity etc. In this specific CA Criterion, the Consequences of some of the described items (such as Hospitals, Schools, Public Transportation) are evaluated directly in the Impact Analysis module as they can be casted as Objects in the i2Sim tool.

CA Criterion Sector 3: Economy. The economic sectors are defined by using the Eurostat NACE metadata[3] (in Italian known as ATECO Index). These data allow describing at a very fine grain the different industrial sectors. These sectors could be, at the same time, put together to form larger and larger areas: the integration could be made according to some specific thematic issue.

[3] The Statistical classification of economic activities in the European Community, abbreviated as NACE, is the nomenclature of economic activities in the European Union (EU); the term NACE is derived from the French Nomenclature statistique des activités économiques dans la Communauté européenne. Various NACE versions have been developed since 1970.

In a first instance, we will integrate according to the usual division in:

- ✓ Primary activities (agriculture, farming);
- ✓ Secondary activities (all production systems, plants of different production goods etc.)
- ✓ Tertiary activities (commerce, services etc.)

The Consequences on these CA Criterion elements will be evaluated on the bases of their punctual (or statistical) representation in a given area affected by the Crisis Scenario.

Periodical national Statistical Surveys, based on NACE ontology, allow to have available direct values (i.e., GDP produced per day) or, indirectly, to define SAWI index and the fraction $r_k(t_{ij})$ of relevance of specific technological or energetic supply for allowing production etc.

CA Criterion 4: Environment. Consequences on the environment will be estimated only in the case in which to a given Critical Scenario can be associated some direct interaction between CI and the environment. In fact, in some cases, a CI fault can be associated to some specific accidents (e.g., explosion, fire, leakage of toxic contents into the sea or other water basins etc.). In these cases, the CAm will attempt to estimate the area affected by pollution, the potential damage (when fires are concerned) to forests and/or to special interest areas (National Parks, areas subjected to special attentions etc.).

4.2.2 The Grade Estimator

After having evaluated Consequences using the *Consequence Estimator* (Equation 16), the DSS provides a Consequence Vector ***C***. Let us assume to have, for each element of the ***C*** vector, a **threshold vector T** which, for each type of Consequence, identifies a "grade" expressed into a "scale" reflecting the severity of the expected Consequences for a given Criteria element.

In order to express the severity of the expected without mixing consequences of different CA criteria, the Grade Estimator associates a "severity grade", called **Consequence Grade *G*** that evaluates the severity of the scenario according to 5 grades as described in the following:

- ***G*** = 1: No significant Consequences
- ***G*** = 2: Consequences can be detected in extension OR in duration. In any case, their extension is lower than the threshold identified in the T vector
- ***G*** = 3. Consequences can be detected in extension AND in duration. In any case, their extension is lower than the threshold identified in the T vector;
- ***G*** = 4. Consequences can be detected in extension AND in duration. Their extension is higher than the threshold identified in the T vector in, at least, one Criteria element;
- ***G*** = 5. Consequences can be detected in extension AND in duration. Their extension is higher than the threshold identified in the T vector in many (even if not in all) Criteria elements.

The Consequence Grade is thus an expression of a twofold characterisation in terms of extensions (spatial, number of affected items) and duration.

If $G < 3$ the scenario is identified as "**Light Crisis**" and the DSS will provide indications according to the Light Crisis Protocol. If $G \geq 3$ the scenario is identified as "**Severe Crisis**" and the DSS will provide indications and support according to Severe Crisis Protocol.

The Severity of a specific crisis, other than being measured in terms of Consequences, is also specified to the CI Operators and Emergency managers in terms of the availability of Resources in the field needed to operate for the restoration of the infrastructures and the restoration of Services. When Resources are inadequate to respond to a Crisis, the DSS attempts to define some specific strategy to reduce the impact of Resources scarcity in the crisis management.

Resources are defined as the set of technical teams available for operating in the field and/or tools which should be used to mitigate or remove the problem, able to restore the Service, such as UPS, which can be available to Operators for a rapid deployment on the Crisis field and produce restoration actions. **Available** Resources, however, should be compared with **Necessary** Resources, i.e. those needed to restore the situation to its equilibrium condition.

Recalling Figure 18, it is important to notice that the B_4 block first evaluates the duration of outages considering an infinite number of resources $\mathbf{R}^{\infty}$ available to CI operators in order to produce the Impact vector $\mathbf{Q^0}$.

In fact, when dealing with the identification of outage duration $T_1(t_{ij})$, the systems makes recourse to a specific database containing the typical restoration time of given CI components, on the bases of available statistical data on operation timings. Nothing is said with respect to the availability of Resources whose action allows restoring the components.

With these premises, the outcome CAm that is the result of the first Impact Analysis consisting of the Consequence Vector $\mathbf{C^0}$ and the Consequence Grade $\mathbf{G^0}$, only provides a lower limit to the duration of the crisis. In fact, the CAm takes for granted the availability of a sufficient number of Resources, which, being available on the field, would allow the simultaneous restoration of all the damaged elements.

This, indeed, is not always the case, particularly in Severe Crisis where many different CI components are involved. In this respect, in case of a predicted Severe Crisis, the DSS performs a comparison between the predicted **Q** vector and the available Resource vector **R** in order to check if the critical situation could be solved by an assumption of availability of "infinite resources".

In situations where **dim[Q] < dim[R]** a sufficient number of Resources is available and restoration can be performed in the "infinite resources" limit.

If, otherwise, **dim[Q] > dim[R]**, the system of available Resources **is not** sufficient to simultaneously provide support to the number of CI components involved in the crisis scenario. This implies the need of providing a ***resources optimisation strategy*** enabling to cope with the problem of allotting the available Resources to a number of CI components through a "sequence" of actions (which CI element restoration should come first) to be performed on the bases of a Fitness Function, enabling to estimate the goodness of the proposed solution (i.e., the proposed "sequence of actions"). This issue is analysed in the following Section.

4.2.3 The Consequences Optimisation procedure

The DSS provides the end-users of a Resource Optimisation procedure, is applied in those cases the crisis is considered severe to find a (sub)-optimal allocation of resources to the problem of minimising the consequences. This can be stated in the following way.

Let us consider Q_i facilities (i = 1, N) which should be simultaneously visited (or repaired) by R_j (j = 1,..,K) resources, where N > K (or even N >> K).

The optimal solution of this problem would be represented by a sequence of interventions S_l (l = 1,…, N) enabling the complete restoration of the systems, with the requirement of producing the smallest possible Consequences for the 4 Criteria.

The sequence S_l can be described as a sequence according to which the CI components are restored (in simultaneous groups of K at a time, being K the number of available resources). It is easy to understand that different restoration sequences could produce different Consequences: some sequences could be preparatory for other restoration and/or enabling some action to be performed more rapidly. In other terms:

$$\{S_{\mathrm{l}}\} = \{Q_1(t_1), Q_2(t_2), \dots, Q_{\mathrm{K}}(t_2), Q_{(\mathrm{K}+1)}(t_2), \dots, Q_{2\mathrm{K}}(t_2), Q_{(2\mathrm{K}+1)}(t_3), \dots, Q_{\mathrm{N}}(t_{\mathrm{m}})\}$$

Equation 18: Sequences of Actions S.

indicating that the first K elements will be restored starting from time t_1, the second group of K elements in the subsequent time t_2 and so on, until the total number of N sites is restored.

In general terms, the optimal solution $\{\tilde{S}_1\}$ will be:

$$\{\tilde{S_l}\}: C_l \quad is \quad minimum$$

As shown in Figure 18, the algorithm implements a loop where the space of solutions of $\{\tilde{S}_1\}$ sequences is explored and the vector of Consequences ***C*** compared to take the sequence that minimises the Consequence ***C***. The output of the optimisation procedure will be the optimal solutions $\tilde{Q}$, $\tilde{S}$ and $\tilde{C}$.

The problem is thus shifted to the definition of a specific metrics for comparing the Consequences vector ***C***. This is covered in the next Section.

4.2.3.1 Consequences Metrics

A major problem arising in this context is the definition of a metrics allowing comparing a multi-dimensional Vector whose elements are NOT expressed in the same units. This problem arises when performing the optimisation procedures for selecting the optimal sequence for restoring in case of limited available Resources.

The problem could be circumvented by identifying "consequences thresholds" (different for the different vector dimensions) given by a Consequence vector C_l whose elements are always numbers. Such vector expresses the extent of the Consequence, in a given Sector, scaled on some specific threshold. A scaled Consequence vector has the advantage to allow the definition of a Norm. Again, some further assumptions are needed to allow the comparison between Norms of different Vectors. In this Section, we will attempt to solve this problem.

In a usual Euclidean vector space, we could attribute the measure of a Vector to its Norm. Euclidean Norm comparison would allow comparing vectors and identifying if vector A is smaller than vector B. Although having been reduced to scalars, the components of the Consequences vectors are "reminiscent" of their diverse origins. As such, a Norm based on the sum of the Consequence vector components would put together Consequences of different ***Criteria*** which, as said, should be avoided.

To circumvent this problem, let us introduce a different Norm, called "**Maximum Norm**" $||x||_\infty$ defined as follows:

$$||x_\infty|| = max(x_1, \dots, x_{\mathrm{M}})$$

Equation 19: Maximum norm.

where M is the total dimension of the Consequence Vector i.e., is the total sum of all the Criteria elements which are simultaneously considered in the Consequence Analysis.

Using this Norm, where the highest Consequence component is extracted as a measure of the weight of the Crisis, a Consequences comparison could be attempted with the following recipes.

Let us assume that S1 and S2 are the optimising sequences to be compared and x_1 and x_2 (belonging to C space) are the vectors representing the Consequences resulting from the application of the two sequences S1 and S2 respectively.

Let us consider the maximum norm of the two vectors:

$$||x_1|| = C_i^{(1)}, \qquad ||x_2|| = C_j^{(2)}$$

indicating that the "maximum" component *ij* of the Consequence vector x_1 is C_i and C_j for the vector x_2. The usual comparison between scalars could be used to determine which of the actions sequences produces the minimum Consequence.

Using this Norm, it is easy to take under control the fate of "social" consequences, which are the type of Consequences which would like to underpin; by acting on the specific threshold, we could keep to a very small value the threshold in all of the Social Sector components, their scaled Vector components will be thus constantly larger (in average) with respect to other's Sectors components, allowing to the societal-related Consequences to determine the size of the Consequence Vectors and thus conditioning the acceptation (or rejection) of a given Sequence of Actions if they produce a too large societal Consequences.

4.3 Consequence Analysis DB Conceptual Schema

The Consequence Analysis Module relies on a database that will be described hereafter. To ensure that it can be interfaced with the WebGIS User Interface, the database will be a PostgreSQL database.

The DB logical diagram is shown in the ANNEX III – CONSEQUENCE ANALYSIS DB SCHEMAS Section. The design of the database for consequences analysis and the data engineering process has been one of the crucial and most difficult task as different considerations and analysis need to be take into account. In fact, the design of the database for CI related Consequences is based on the idea that it is necessary to find a compromise between the availability of data and its granularity. Moreover, the useful level of detail in the final CA report has to be considered. The higher the required detail, the larger and more detailed will be the data needed in the database and the more difficult to have it. To improve usability, it is useful not to give information not strictly needed. Therefore, the DB design have been kept as much simple as possible, in order to manage lack of information.

According to the data ontology described in Figure 2, the conceptual schema includes a number of entities ideally belonging to different "levels":

- Infrastructure (Power, Telco, Water, Gas, Transportation): summarising the current status of service of the different infrastructure components with the granularity and detail needed by the Consequence Analysis module. In particular, the infrastructure tables have to store the result of the DSS B_3 functional brick (i.e. the damage scenario data).
- Socio-economic data of the area of interest. These tables (i.e. the Residential and Population, Non Residential and Industry tables) are static data in the sense that are filled only once and updated with a low frequency. Most important, the tables are designed in a way such that to show the dependency from the infrastructures (e.g. the number of people and the different category of people that depend to a specific electric secondary substation).
- CA configuration tables that contain data useful for consequence computation to reduce information to be hardcoded (SAWI indexes, Default values, interesting information for the report, weights etc.)

In the following tables, primary keys are specified with *.

4.3.1 Entity: Power

Entity name	Entity description
Power	It stores information about the access points of the electrical power infrastructure (mainly secondary cabins, primary cabin only if relevant), needed for the calculation of the Consequence Analysis metrics and for reporting.

Attributes	Comment
ID *	To improve interoperability, ID is the one provided by the operator. Example CS004537 for a secondary cabin of ACEA distribution grid
Owner *	To avoid ID collision, the owner has to be specified. Example ACEA
Nickname	To improve readability from the operator, value taken from their system. Example "Montemario - Sip" for cabin id CS004537
kV	The operating voltage level of the cabin Example: 20 - 8.4
Census_section	We have statistical data about population divided by census section. To give an idea of detail level, Rome is divided in about 12,000 census section.
STATUS	1 if working, 0 if not working. This field could trigger the analysis and allows making a report about infrastructure status.

4.3.2 Entity: Telco

Entity name	Entity description
Telco	It stores information about the access points of the Telco infrastructure (mainly BTS), needed for the calculation of the Consequence Analysis metrics and for reporting.

Attributes	Comment
ID*	To improve interoperability, ID is the one provided by the operator.
Owner*	To avoid ID collision, the owner has to be specified. Example: TELECOM
Nickname	To improve readability from the operator.
Technology	UMTS/xDSL
Census_section	We have statistical data about population divided by census section. To give an idea of detail level, Rome is divided in about 12,000 census sections.
STATUS	1 if working, 0 if not working. This field could trigger the analysis and allows making a report about infrastructure status.

4.3.3 Entity: Water

Entity name	Entity description
Water	It stores information about the access points of the Water infrastructure, needed for the calculation of the Consequence Analysis metrics and for reporting.

Attributes	Comment
ID*	To improve interoperability, ID is the one provided by the operator.
Owner*	To avoid ID collision, the owner has to be specified. Example: ACEA
Nickname	To improve readability from the operator.
Census_section	We have statistical data about population divided by census section. To give an idea of detail level, Rome is divided in about 12,000 census section.
STATUS	1 if working, 0 if not working. This field could trigger the analysis and allows making a report about infrastructure status.

4.3.4 Entity: Gas

Entity name	Entity description
Gas	It stores information about the access points of the Gas infrastructure, needed for the calculation of the Consequence Analysis metrics and for reporting.

Attributes	Comment
ID*	To improve interoperability, ID is the one provided by the operator.
Owner*	To avoid ID collision, the owner has to be specified. Example: ENI
Nickname	To improve readability from the operator.
Census_section	We have statistical data about population divided by census section. To give an idea of detail level, Rome is divided in about 12,000 census section.
STATUS	0 if working, 1 if not working. This field could trigger the analysis and allows making a report about infrastructure status.

4.3.5 Entity: Transportation

Entity name	Entity description
Transportation	It stores information about the relevant access points of the different Transportation infrastructures, needed for the calculation of the Consequence Analysis metrics and for reporting.

Attributes	Comment
PoiID*	To improve interoperability, ID is the one provided by the operator/data owner.
Data Owner*	To avoid ID collision, the owner has to be specified. In case of different owners have the same PoI, the operator should be privileged to foster interoperability. Example: ATAC, TeleAtlas (ATAC privileged)
Type/Feattyp	Railway, Subway, Road…
Name	Example: MetroA/Termini
Longitude	Example: 12.41
Latitude	Example: 41.26.
Census_section	We have statistical data about population divided by census section. To give an idea of detail level, Rome is divided in about 12,000 census section.
STATUS	1 if working, 0 if not working. This field could trigger the analysis and allows making a report about infrastructure status.

4.3.6 Entity: Residential

Entity name	Entity description
Residential	It stores data about groups of buildings ideally connected to a unique combination of Power, Telco, Water and Gas access points. It is calculated starting from the census data and equally distributing buildings (and then people) to the different combination of access points.

Attributes	Comment
ID*	In the data provided by the Italian National Institute of Statistics, there is a line for a (small) group of buildings. The ID could assigned as "census section"+"_"+Nb of buildings
Data Owner*	This field is needed to keep track of the source of information Example: ISTAT
Census Section	Census section id, that is the reference to the data provided by the Italian National Institute of Statistics
Power Access Point ID	The secondary cabin of the Electrical infrastructure that delivers the service to the final users (the group of buildings of this line).
Telco Access Point ID	The last element (access point) of the Telco infrastructure that delivers the service to the final users (the group of buildings of this line).
Water Access Point ID	The access point of the Water infrastructure that delivers the service to the final users (the group of buildings of this line).
Gas Access Point ID	The access point of the Gas infrastructure which delivers the service to the final users (the group of buildings of this line)

4.3.7 Entity: Industry

Entity name	Entity description
Industry	It stores data about industrial activities ideally connected to a unique combination of Power, Telco, Water and Gas access points. It is calculated starting from the industry census data and distributing industrial activities to the different combination of access points.

Attributes	Comment
NACE Code	Identifier of the type of activity.
Category/ATECO group	Example: Manufacture, ICT based activities, Tourism
Data Source	This field is needed to keep track of the source of information Example: ISTAT
Nb of companies	The number of activities in the area.
Average Annual Income	Average annual income of the single company. Data is usually available as cumulated turnover for all the
Annual Income Source	Provided/Estimated. To keep track of the quality of the information.
Census section*	Census section id, that is the reference to the data provided by the Italian National Institute of Statistics.
Power Access ID	The last element (access point, in general secondary cabin) of the Electrical infrastructure that delivers the service to the final users (the group of activities of this line).
Telco Access Point ID	The last element (access point) of the Telco infrastructure that delivers the service to the final users (the group of activities of this line).
Water Access Point ID	The access point of the Water infrastructure that delivers the service to the final users (the group of activities of this line).
Gas Access Point ID	The access point of the Gas infrastructure that delivers the service to the final users (the group of activities of this line).

4.3.8 Entity: Non Residential

Entity name	Entity description
Non Residential	It stores data about single companies and services, for example all the relevant POI provided by TeleAtlas. In addition to Post Offices, Schools, Pharmacies, Hospitals, Public Transportation, it includes Museums, Cinemas, Restaurants etc. in order to give the stakeholders a clue about the impacted entities so that they can put in the right perspective the provided consequence figures.

Attributes	Comment
PoiID*	Identifier of the Point of Interest. It can be the ID by TeleAtlas or the Trade Register Number of the Chamber of Commerce
Data Owner *	This field is needed to keep track of the source of information Example: TeleAtlas
PoiType/Feattyp	Hospital, PostOffice, Bank, ATM, School, Pharmacy, Supermarket, Shop, Police Station, Airport, Monuments
Category	Service, Commercial, Industrial
Name	The name of the society
Longitude	Example: 12.41
Latitude	Example: 41.26.
Census section	Census section id, which is the reference to the territory area identified by the Italian National Institute of Statistics.
Power Access ID	The last element (access point, in general secondary cabin) of the Electrical infrastructure that delivers the service to the PoI.
Telco Access Point ID	The last element (access point) of the Telco infrastructure that delivers the service to the PoI.
Water Access Point ID	The access point of the Water infrastructure that delivers the service to the PoI.
Gas Access Point ID	The access point of the Gas infrastructure that delivers the service to the PoI.

4.3.9 Entity: Population

Entity name	Entity description
Population	It stores data about people living in the group of buildings of the table Residential. It is calculated starting from the census data. Attributes are selected according to the indicators highlighted as relevant in [19] Data is available in each European country by the National Institute of Statistics. A customisation table could be created in order to take into account stakeholders need about relevant/non relevant information in the report and in the GIS graphical user interface..

Attributes	Comment
Residential Build ID	To link data with the table Residential
Data Owner	
Census section	Census section id that is the reference to the territory area identified by the Italian National Institute of Statistics.
Tot Residents	Data needed for the most basic metrics.

Women	
Age <5	
Age > 67	
Age > 67 / Women	
Employed	Data needed to elicit presence at home in some hours of the day.
Students	
Housewives	
Retired people	
Nb of families	This data is needed if demand profile need to be really specific
Families with 1 person	
Families with 2 people	
Families with 3 people	
Families with 4 people	
Families with 5+ people	
Families living on 1st floor	This information has to be elicited. Needed for estimating casualties during earthquake, if relevant.
Families living on 2nd floor	
Families living on 3rd floor	
Families living on 4th+ floor	
People with disability	Number of people estimated on the basis of the national percentage of disabled people

4.3.10 Entity: Social Figures

Entity name	Entity description
Vulnerability	It stores the output of the Social figures of the consequence analysis to be displayed in the WebGIS GUI (number and type of impacted people for each census section or cabin). It will separately store people (divided by census section) impacted by each infrastructure out of service. It is based on table Population

Attributes	Comment
Infrastructure Loss	The impact following the loss of 2 infrastructures (for example Power and Water) is not the sum of the impacts for the 2 infrastructures separately. For example, if power is needed to operate a pump for water, the loss of power means you don't care if you have water… Therefore in this attribute the overall loss is taken into account. Example: Power, Telco, Water, Gas, Power&Telco, Power&Water, Power&gas, Telco&Water, Telco&Gas, Water&Gas, Power&Telco&Water, Power&Telco&Gas, Power&Water&Gas, Power&Telco&Water&Gas.
Census section	Census section id that is the reference to the territory area identified by the Italian National Institute of Statistics.
Tot Residents	Raw figures: Nb of impacted people
Women	
Age <5	
Age > 67	
Age > 67 / Women	
People with disability	
C_TotResidents	Consequence metric value calculated for the whole population.
C_age<5	Consequence metric value calculated for the segment of population: children aged less than 5 years old.
C_age>67	Consequence metric value calculated for the segment of population: people older than 67 years old.
C_women	Consequence metric value calculated for the segment of population: women
C_disabled	Consequence metric value calculated for the segment of population: disabled

4.3.11 Entity: Economic Figures

Entity name	Entity description
Economic Figures	It stores the output of the Economic figures of the consequence analysis to be displayed in the WebGIS GUI (number and type of impacted commercial activities for each census section or cabin). It will separately store companies (divided by census_section) impacted by each infrastructure out of service. It is based on tables Industry.

Attributes	Comment
Infrastructure Loss	The impact following the loss of 2 infrastructures (for example Power and Water) is not the sum of the impacts for the 2 infrastructures separately. For example, if power is needed to operate a pump for water, the loss of power means you don't care if you have water… Therefore in this attribute the overall loss is taken into account. Example: Power, Telco, Water, Gas, Power&Telco, Power&Water, Power&gas, Telco&Water, Telco&Gas, Water&Gas, Power&Telco&Water, Power&Telco&Gas, Power&Water&Gas, Power&Telco&Water&Gas
Census section	Census section id, that is the reference to the territory area identified by the Italian National Institute of Statistics
Category/NACE group	Example: Manufacture, ICT based activities, Tourism
Nb of activities/companies	Number of the relevant companies in table Industry
Consequence value	Consequence metric value calculated for the whole NACE group
Total yearly income	Sum of the single income of relevant companies in table Industry

4.3.12 Entity: Default Values

Entity name	Entity description
Default values	It stores default status values for the infrastructure, supporting the reset of the scenario, as it is used to automatically write the needed queries without hardcoding them.

Attribute	Example
Table	Power
Column	Status
Type	Short
Value	1

5 Conclusion

This document describes the methodologies implemented within the CIPRNet DSS and the data needed to perform vulnerability analysis of CI components. The proposed methodologies have been applied mainly to the electrical distribution domain and it has been showed how they allow transforming natural events manifestations (e.g. heavy rain) to CI damages.

Then, the document describes a novel methodology for the consequence analysis of CI reduction and/or loss of Quality of Service on the society. In particular the methodology introduces the concept of "Consequences" of a Critical Scenario in terms of "societal" wealth reduction, associated to the expected impacts on CI-supplied Services, under different viewpoints called criterion (i.e. citizens, services, economy and environment).

In Chapter 2 we first recalled the architecture and the main functionalities of the DSS and showed the relative data layer required to implement each functionality. We then discussed implementation details and security solutions to improve the security of the database.

In Chapter 3 we discussed the data structure required to store the vulnerability of the various components and presented the preliminary results of our vulnerability analysis on specific CI against rainfalls and earthquakes.

In Chapter 4 we presented some metrics to implement the consequence analysis module. We described the different sectors where we implemented our metrics and shown how the estimated consequences could be store in the database. In particular, we focussed in CI related Consequences being No-CI related Consequences analysis addressed in a further document.

Both vulnerability and consequence analysis methodologies will be applied to new CI networks and sectors as new data will be collected within the CIPRNet DB.

The estimate of CI related Consequences has imposed the development of a novel theoretical framework. In fact, as CI related damages can be amplified by the transformation of Damages into Impacts and the subsequent needs of measuring the Consequences produced by Impacts, we have developed the theory of SAW indices allowing to estimate the reduction of well-being (I.e. some measurable Consequences) induced by the lack of primary services. The new framework of the SAW indices will be tested in the project and, if properly validated, will highly contribute to the improvement of measuring techniques of Consequences of crisis scenarios.

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ANNEX I – LIST OF DATABASE CONTENTS

Type of data	Data format	Data provider (source)	Data collector	End user	Operating Platform	Processing application	Protection mode	Purpose of processing	Storage lifetime	Disposal measure	Confidentiality level	Source country	Destination country
CI data (power, gas and railway: networks and elements)	GIS layers	PLATTS	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Construct CI dependency models. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	License conditions apply	NA	Italy, The Netherlands, Germany
CI data (power substations and sample distribution lines)	GIS layers	ACEA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Construct CI dependency models. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	ENEA restricted	Italy	Italy
CI Data (power/telco interconnections, BTS, Subs. remote controlled)	GIS layers	ACEA and Telecom Italia	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Construct CI dependency models. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	ENEA restricted	Italy	Italy
Real-time air traffic situation (flight tracking)	GIS layers	ENEA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	ENEA restricted	Italy (Lazio Region)	Italy (Lazio Region)

Type of data	Data format	Data provider (source)	Data collector	End user	Operating Platform	Processing application	Protection mode	Purpose of processing	Storage lifetime	Disposal measure	Confidentiality level	Source country	Destination country
Seismic event data (epicentre and magnitude), PGA and Shake Maps	Various	INGV (Italian National Institute of Geophysics and Volcanology)	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication required	GIS-based visualisations. Quantification of damages related to earthquakes.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Earthquake catalogue, Zones and Seismic Risk Maps	GIS layers and OGC Services	INGV	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Quantification of damages related to earthquakes.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Vulnerability maps (Buildings and CI)	GIS layers	ENEA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	CIPRNet restricted	Italy	Italy
Volcanic plume mapping (ash mass, concentration and distribution)	GIS layers	INGV	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Quantification of damages and consequences.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	CIPRNet restricted	Italy	Italy
Forecasting data and maps (precipitation, temperature, wind, solar radiation, etc.)	NetCDF	Himet Srl DPC ENEA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Threats prediction (related to meteorological events). PV potential power production assessment.	Minimum: CIPRNet runtime Medium: VCCC runtime And other projects	Standard	ENEA restricted	Italy	Italy
Nowcasting (rainfall/lightning) data and maps	NetCDF	Himet Srl DPC	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	Authentication based on encrypted password. Periodic backup on another internal server.	GIS-based visualisations. Threats prediction (related to rainfall/lightning events).	Minimum: CIPRNet runtime Medium: VCCC runtime And other projects	Standard	ENEA restricted	Italy	Italy

Type of data	Data format	Data provider (source)	Data collector	End user	Operating Platform	Processing application	Protection mode	Purpose of processing	Storage lifetime	Disposal measure	Confidentiality level	Source country	Destination country
Census Data, Parcels and Indicators	Shapefile and Tables	ISTAT (Italian National Institute of Statistics)	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Quantification of consequences on population and buildings.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Road Network and Railways	GIS layers	ISPRA SINANET Octo-Telematics ENEA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Territorial characterisation. Vulnerability assessment. Quantification of damages.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Traffic Now-casting	Web-Service	Octo-Telematics ENEA	ENEA	ENEA	-	geoSDI and DSS	Authentication based on encrypted password.	Info-mobility visualisation.	Minimum: CIPRNet runtime Medium: VCCC runtime Maybe for other projects	Standard	ENEA restricted	Italy (Rome)	Italy (Rome)
Points of interest (Schools, Hospitals and Pharmacy, Banks, ATM, etc.)	GIS layers and Tables	OpenStreetMap TeleAtlas	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	OpenStreetMap: no specific protection (Open Data) TeleAtlas: Authentication based on encrypted password.	GIS-based visualisations. Territorial characterisation. Vulnerability assessment. Quantification of damages.	as long as needed in projects	Standard	OpenStreetMap: Open Data TeleAtlas: License conditions apply	Italy	Italy
Corine Land Cover - CLC (2006)	GIS layers (shp)	EEA European Environment Agency	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Territorial characterisation.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Historical data of rainfall and thermometry (2003-2013)	GIS layers and Tables	Lazio Region Hydrographic office	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Vulnerability assessment.	as long as needed in projects	Standard	Unclassified	Italy	Italy

Type of data	Data format	Data provider (source)	Data collector	End user	Operating Platform	Processing application	Protection mode	Purpose of processing	Storage lifetime	Disposal measure	Confidentiality level	Source country	Destination country
Inventory of Landslide Phenomena in Italy - IFFI	OGC Services	ISPRA (Italian Institute for Environmental Protection and Research)	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Quantification of damages.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Hydrogeological Risk & Hazard Maps (PAI)	OGC Services	ISPRA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations. Quantification of damages.	as long as needed in projects	Standard	Unclassified	Italy	Italy
Basic GIS Layers (DBPrior10k) and thematic maps (geology, land cover, etc.)	Shapefile and OGC Services	ISPRA	ENEA	ENEA	PostgreSQL/PostGIS on Linux Server; Geoserver	geoSDI and DSS	No specific protection (Open Data)	GIS-based visualisations of basic territorial features.	as long as needed in projects	Standard	Unclassified	Italy	Italy

ANNEX II – VULNERABILITY & IMPACT ASSESSMENT DB SCHEMA

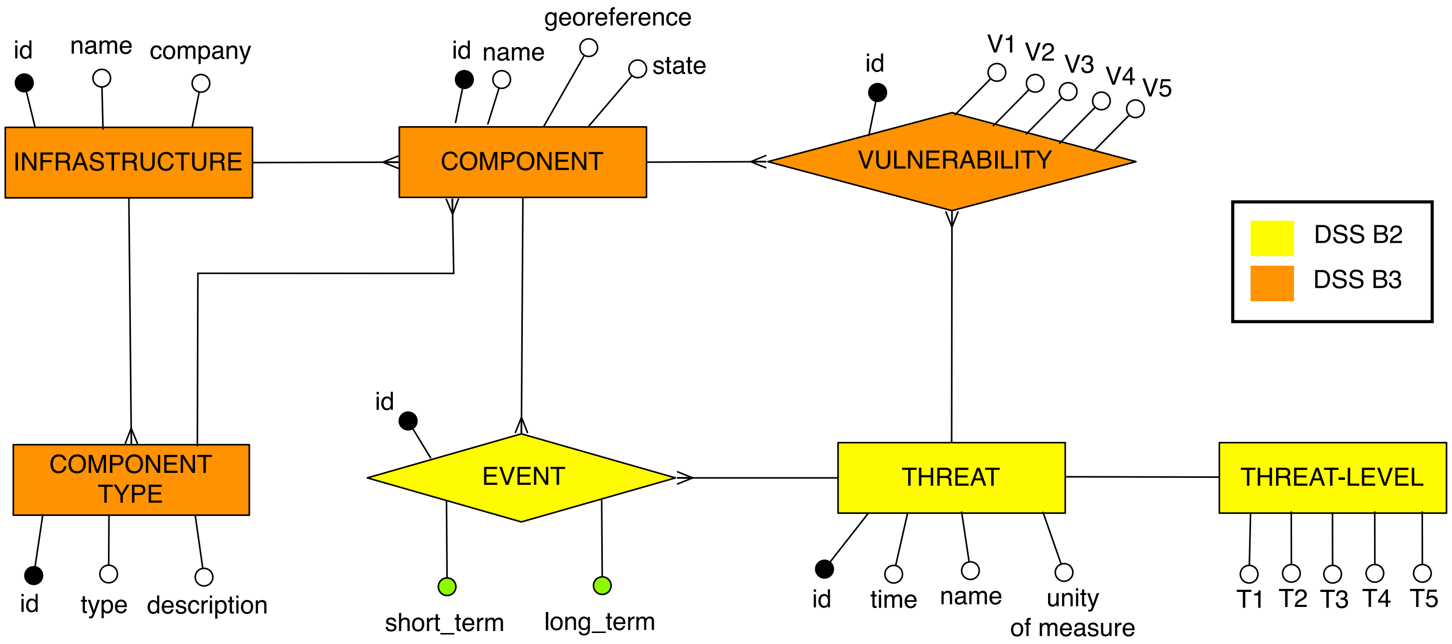

Figure 19: Infrastructure Vulnerability ER Diagram.

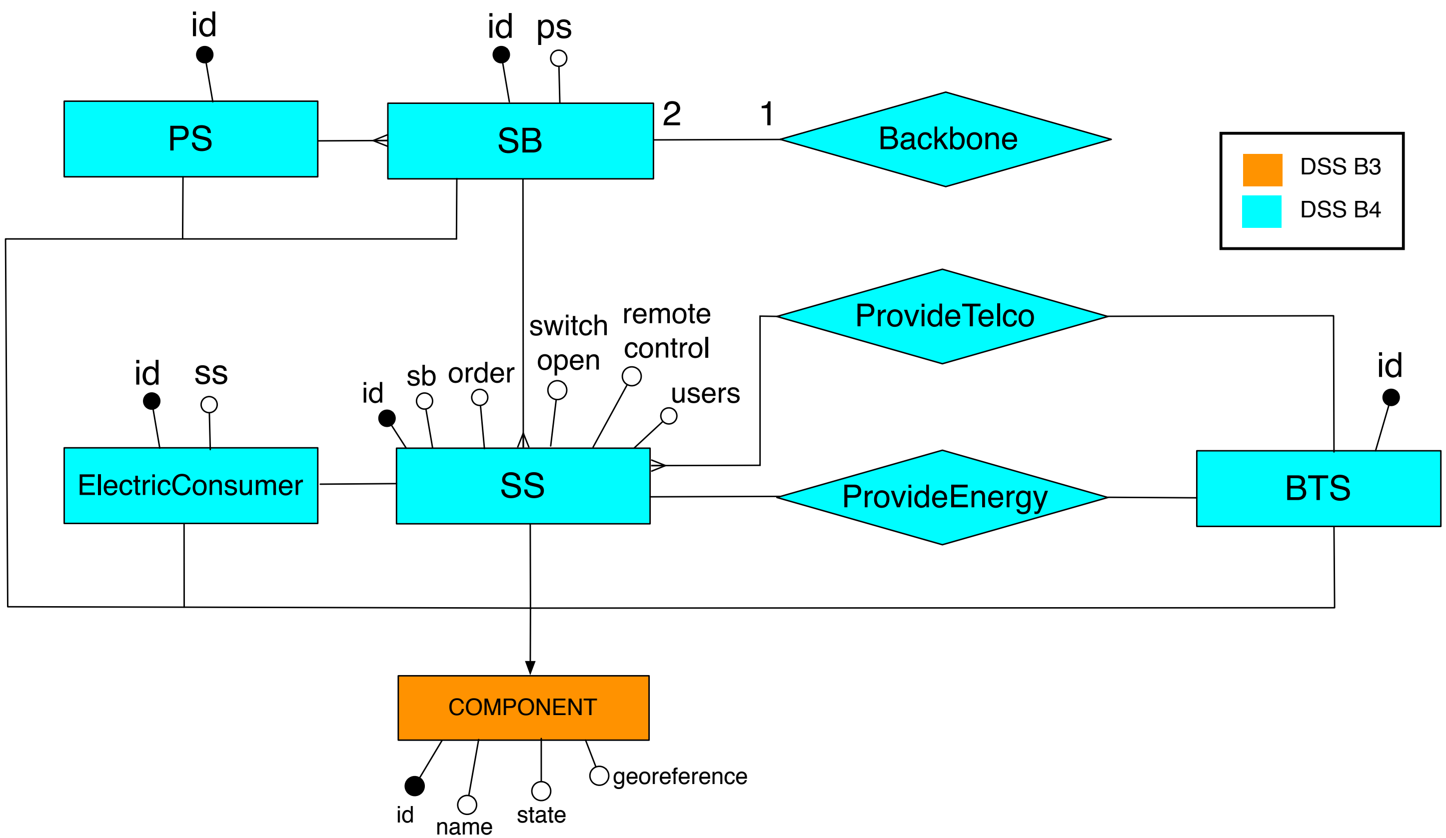

Figure 20: Impact Assessment ER Diagram.

ANNEX III – CONSEQUENCE ANALYSIS DB SCHEMAS

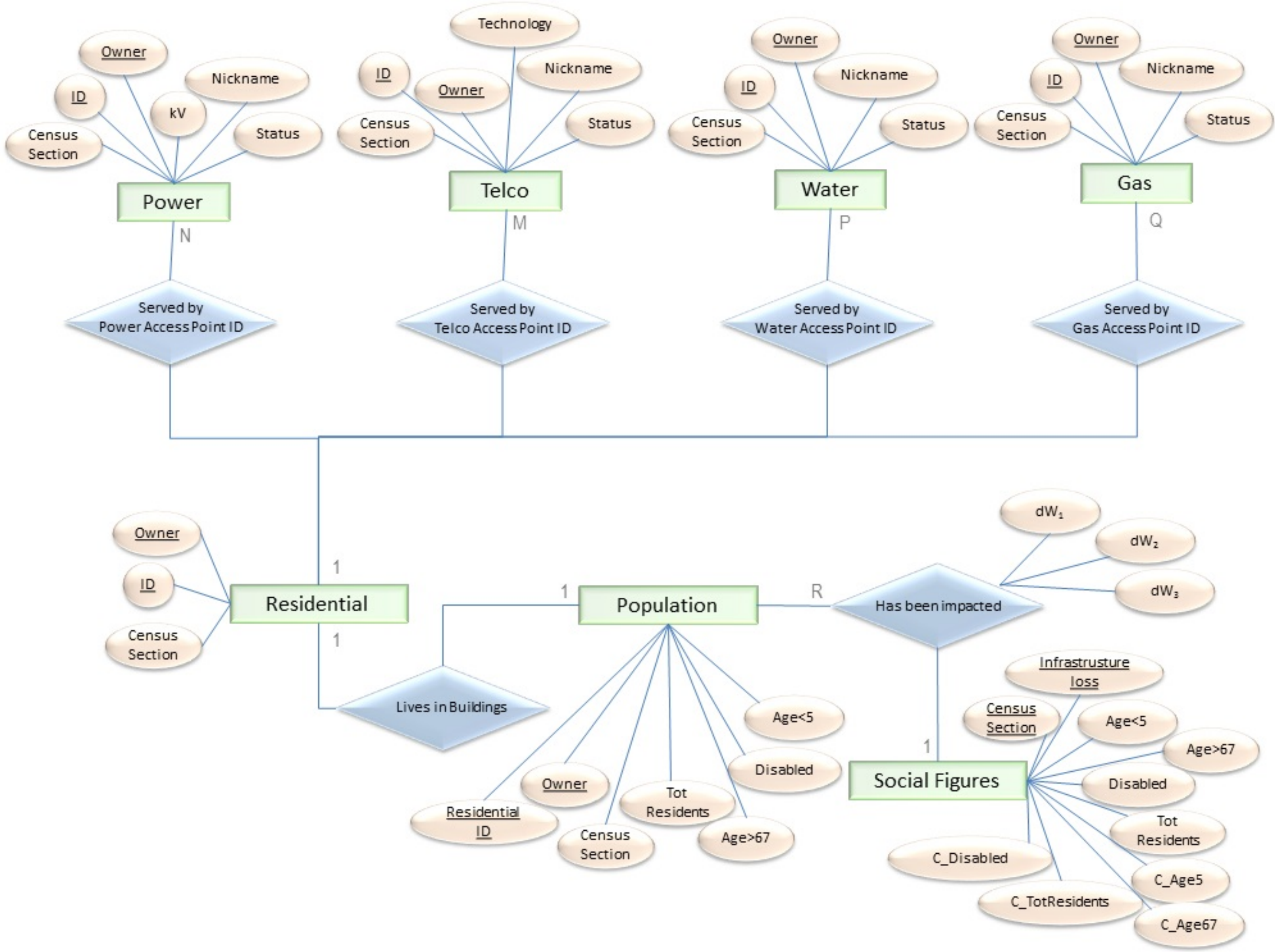

Figure 21: Consequence Analysis ER Diagram 1.

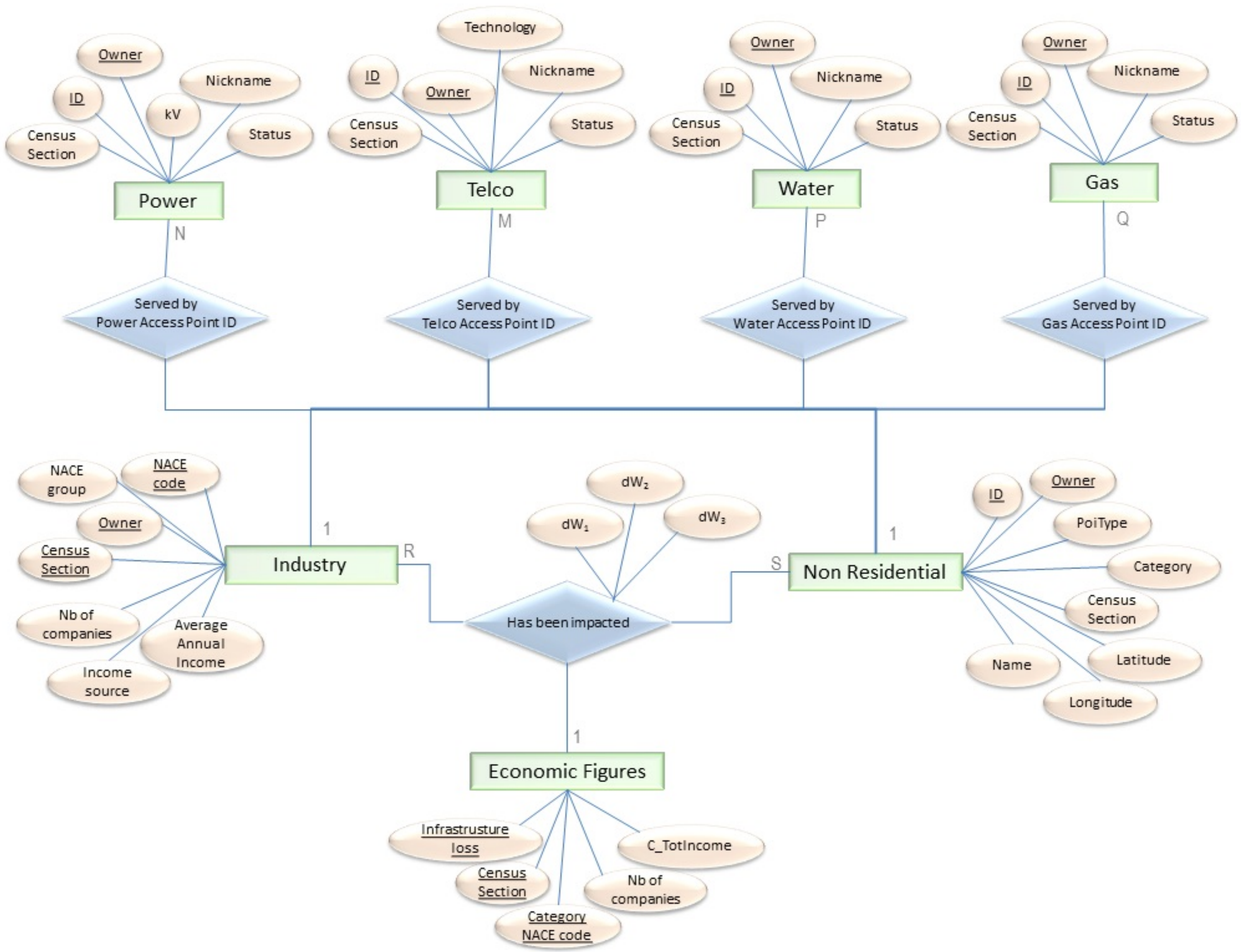

Figure 22: Consequence Analysis ER Diagram 2.

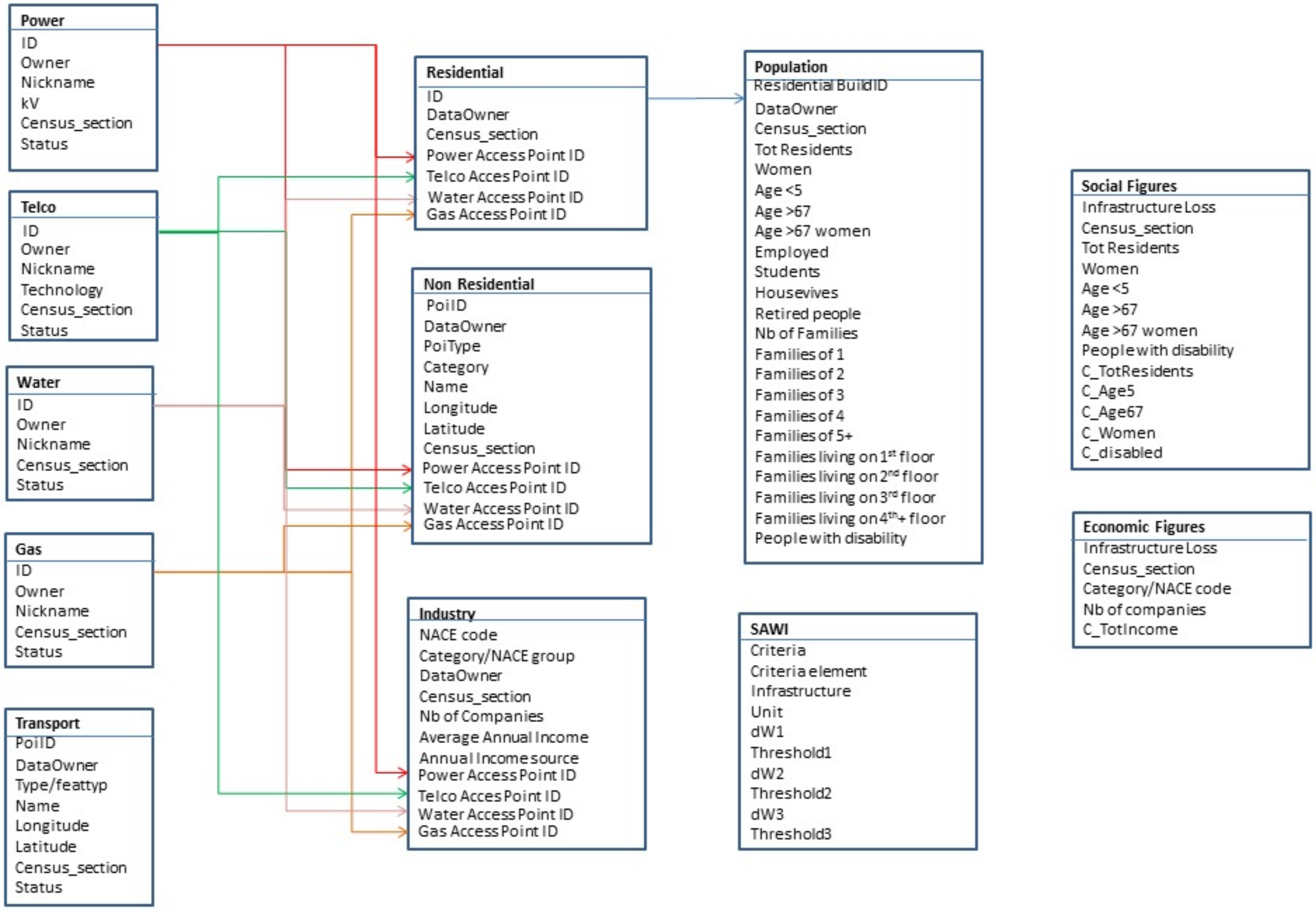

Figure 23: Consequence Analysis DB Logical Schema. The transport table will be further connected when related functional data will be let available.

ANNEX IV – Census Data

A typical example (taken from Italian Census Data on 2001) of ontology (metadata) organisation of the database with respect to Population details in the different census areas is shown:

14° Censimento generale della popolazione e delle abitazioni - Anno 2001
Metadati delle variabili del censimento della popolazione

NOME CAMPO	DEFINIZIONE
COD_PRO	Codice numerico della Provincia
COD_COM	Codice numerico del Comune
PRO_COM	Codice numerico che identifica univocamente il 'comune' nell'ambito del territorio nazionale. Il valore è ottenuto dalla concatenazione del codice provinciale e comunale
SEZ2001	Codice che identifica univocamente la sezione di censimento 2001 nell'ambito del territorio nazionale. Il valore è ottenuto dalla concatenazione del PRO_COM con il campo SEZIONE
SEZIONE	Codice che identifica univocamente la sezione di censimento 2011 nell'ambito di ciascun comune.
P1	Popolazione residente - TOTALE
P2	Popolazione residente - Maschi
P3	Popolazione residente - Femmine
P4	Popolazione residente - Celibi/nubili
P5	Popolazione residente - Coniugati/e
P6	Popolazione residente - Separati/e legalmente
P7	Popolazione residente - Vedovi/e
P8	Popolazione residente - Divorziati/e
P9	Popolazione residente - Maschi celibi
P10	Popolazione residente - Maschi coniugati o separati di fatto
P11	Popolazione residente - Maschi separati legalmente
P12	Popolazione residente - Maschi vedovi
P13	Popolazione residente - Maschi divorziati
P14	Popolazione residente - età < 5 anni
P15	Popolazione residente - età 5 - 9 anni
P16	Popolazione residente - età 10 - 14 anni
P17	Popolazione residente - età 15 - 19 anni
P18	Popolazione residente - età 20 - 24 anni
P19	Popolazione residente - età 25 - 29 anni
P20	Popolazione residente - età 30 - 34 anni
P21	Popolazione residente - età 35 - 39 anni
P22	Popolazione residente - età 40 - 44 anni
P23	Popolazione residente - età 45 - 49 anni
P24	Popolazione residente - età 50 - 54 anni
P25	Popolazione residente - età 55 - 59 anni
P26	Popolazione residente - età 60 - 64 anni
P27	Popolazione residente - età 65 - 69 anni
P28	Popolazione residente - età 70 - 74 anni
P29	Popolazione residente - età > 74 anni
P30	Popolazione residente - Maschi - età < 5 anni
P31	Popolazione residente - Maschi - età 5 - 9 anni
P32	Popolazione residente - Maschi - età 10 - 14 anni
P33	Popolazione residente - Maschi - età 15 - 19 anni
P34	Popolazione residente - Maschi - età 20 - 24 anni
P35	Popolazione residente - Maschi - età 25 - 29 anni
P36	Popolazione residente - Maschi - età 30 - 34 anni
P37	Popolazione residente - Maschi - età 35 - 39 anni
P38	Popolazione residente - Maschi - età 40 - 44 anni
P39	Popolazione residente - Maschi - età 45 - 49 anni
P40	Popolazione residente - Maschi - età 50 - 54 anni
P41	Popolazione residente - Maschi - età 55 - 59 anni
P42	Popolazione residente - Maschi - età 60 - 64 anni
P43	Popolazione residente - Maschi - età 65 - 69 anni
P44	Popolazione residente - Maschi - età 70 - 74 anni
P45	Popolazione residente - Maschi - età > 74 anni
P46	Popolazione residente di 6 anni e più -TOTALE
P47	Popolazione residente di 6 anni e più - Laurea o diploma universitario o terziario di tipo non universitario
P48	Popolazione residente di 6 anni e più - Diploma di scuola secondaria superiore
P49	Popolazione residente di 6 anni e più - Media inferiore
P50	Popolazione residente di 6 anni e più - Licenza elementare
P51	Popolazione residente di 6 anni e più - Alfabeti
P52	Popolazione residente di 6 anni e più - Analfabeti
P53	Popolazione residente di 6 anni e più - Maschi - TOTALE
P54	Popolazione residente di 6 anni e più - Maschi - Laurea o diploma universitario o terziario di tipo non universitario
P55	Popolazione residente di 6 anni e più - Maschi - Diploma di scuola secondaria superiore
P56	Popolazione residente di 6 anni e più - Maschi - Media inferiore
P57	Popolazione residente di 6 anni e più - Maschi - Licenza elementare
P58	Popolazione residente di 6 anni e più - Maschi - Alfabeti

Figure 24: Italian Census data 1/3.

P59	Popolazione residente di 6 anni e più - Maschi - Analfabeti
P60	Forze lavoro - TOTALE
P61	Forze lavoro - Occupati
P62	Forze lavoro - Disoccupati e altre persone in cerca di occupazione
P64	Forze lavoro - Maschi
P65	Forze lavoro - Maschi - Occupati
P66	Forze lavoro - Maschi - Disoccupati e altre persone in cerca di occupazione
P68	Occupati per sez A,B - Agricoltura Totale
P69	Occupati per sez C,E - Industria (Estrazione, Produzione energia)
P70	Occupati per sez D - Industria (Manifatturiere)
P71	Occupati per sez F - Industria (Costruzioni)
P72	Occupati - Industria Totale
P73	Occupati per sez G,H - Altre attività (Commercio/riparazioni, Alberghi/ristoranti)
P74	Occupati per sez I - Altre attività (Trasporti/comunicazioni)
P75	Occupati per sez J - Altre attività (Intermediazione)
P76	Occupati per sez K - Altre attività (Immobiliari, professionali, imprenditoriali)
P77	Occupati per sez L - Altre attività (Pubblica Amm., difesa, assicur. sociale)
P78	Occupati per sez M - Altre attività (Istruzione)
P79	Occupati per sez N - Altre Attività (Sanità, Servizi sociali)
P80	Occupati per sez O,P,Q - Altre attività (Servizi pubblici/domestici, org. extraterritoriali)
P81	Occupati per sez - Altre attività Totale
P82	Occupati - Maschi -per sez A,B - Agricoltura totale
P83	Occupati - Maschi -per sez C,E - Industria (Estrazione, Produzione energia)
P84	Occupati - Maschi -per sez D - Industria (Manifatturiere)
P85	Occupati - Maschi -per sez F - Industria (Costruzioni)
P86	Occupati - Maschi -- Industria totale
P87	Occupati - Maschi -per sez G,H - Altre attività (Commercio/riparazioni, Alberghi/ristoranti)
P88	Occupati - Maschi -per sez I - Altre attività (Trasporti/comunicazioni)
P89	Occupati - Maschi -per sez J - Altre attività (Intermediazione)
P90	Occupati - Maschi -per sez K - Altre attività (Immobiliari, professionali, imprenditoriali)
P91	Occupati - Maschi -per sez L - Altre attività (Pubblica Amm., difesa, assicur. sociale)
P92	Occupati - Maschi -per sez M - Altre attività (Istruzione)
P93	Occupati - Maschi -per sez N - Altre Attività (Sanità, Servizi sociali)
P94	Occupati - Maschi -per sez O,P,Q - Altre attività (Servizi pubblici/domestici, org. extraterritoriali)
P95	Occupati - Maschi -- Altre attività Totale
P96	Occupati - Imprenditori e liberi professionisti
P97	Occupati - Lavoratori in proprio
P98	Occupati - Coadiuvanti
P99	Occupati - Lavoratori dipendenti
P100	Occupati - Imprenditori e liberi professionisti in Agricoltura
P101	Occupati - Lavoratori in proprio in Agricoltura
P102	Occupati - Coadiuvanti in Agricoltura
P103	Occupati - Lavoratori dipendenti in Agricoltura
P104	Occupati - Imprenditori e liberi professionisti in Industria
P105	Occupati - Lavoratori in proprio in Industria
P106	Occupati - Coadiuvanti in Industria
P107	Occupati - Lavoratori dipendenti in Industria
P108	Occupati - Imprenditori e liberi professionisti in Altre attività
P109	Occupati - Lavoratori in proprio in Altre attività
P110	Occupati - Coadiuvanti in Altre attività
P111	Occupati - Lavoratori dipendenti in Altre attività
P112	Occupati - Maschi - Imprenditori e liberi professionisti
P113	Occupati - Maschi - Lavoratori in proprio
P114	Occupati - Maschi - Coadiuvanti
P115	Occupati - Maschi - Lavoratori dipendenti
P116	Occupati - Maschi - Imprendenditori e liberi professionisti in Agricoltura
P117	Occupati - Maschi - Lavoratori in proprio in Agricoltura
P118	Occupati - Maschi - Coadiuvanti in Agricoltura
P119	Occupati - Maschi - Lavoratori dipendenti in Agricoltura
P120	Occupati - Maschi - Imprenditori e liberi professionisti in Industria
P121	Occupati - Maschi - Lavoratori in proprio in Industria
P122	Occupati - Maschi - Coadiuvanti in Industria
P123	Occupati - Maschi - Lavoratori dipendenti in Industria
P124	Occupati - Maschi - Imprenditori e liberi professionisti in Altre attività
P125	Occupati - Maschi - Lavoratori in proprio in Altre attività
P126	Occupati - Maschi - Coadiuvanti in Altre attività
P127	Occupati -Maschi - Lavoratori dipendenti in Altre attività
P128	Non appartenente alle forze lavoro - TOTALE
P129	Non appartenente alle forze lavoro - Maschi
P130	Non forze lavoro - casalinghi/e
P131	Non forze lavoro - studenti

Figure 25: Italian Census data 2/3.

P132	Non forze lavoro - Maschi - Studenti
P133	Non forze lavoro - Ritirati dal lavoro
P134	Non forze lavoro - Maschi - Ritirati dal lavoro
P135	Non forze lavoro - Altra condizione
P136	Non forze lavoro - Maschi - Altra condizione
P137	Popolazione residente che si sposta giornalmente nel comune di dimora abituale
P138	Popolazione residente che si sposta giornalmente fuori del comune di dimora abituale
A1	Abitazioni totali
A2	Abitazioni occupate da persone residenti
A3	Abitazioni occupate solo da persone non residenti
A4	Abitazioni vuote
A5	Altri tipi di alloggio-TOTALE
A6	Stanze in totale
A7	Stanze in abitazioni occupate da persone residenti
A9	Abitazioni occupate da persone residenti in proprietà
A10	Abitazioni occupate da persone residenti in affitto
A11	Abitazioni occupate da persone residenti ad altro titolo
A12	Abitazioni occupate da persone residenti con una stanza
A13	Abitazioni occupate da persone residenti con 2 stanze
A14	Abitazioni occupate da persone residenti con 3 stanze
A15	Abitazioni occupate da persone residenti con 4 stanze
A16	Abitazioni occupate da persone residenti con 5 stanze
A17	Abitazioni occupate da persone residenti con 6 o più stanze
A18	Abitazioni totali fornite acqua potabile
A19	Abitazioni totali fornite di gabinetto
A20	Abitazioni totali fornite di vasca da bagno e/o doccia
A21	Abitazioni occupate da persone residenti fornite di una linea telefonica fissa attiva
A22	Abitazioni totali senza acqua potabile e gabinetto
A23	Superficie delle abitazioni totali
A24	Abitazioni occupate da persone residenti fornite di impianto di riscaldamento - TOTALE
A25	Abitazioni totali fornite di impianto di riscaldamento centralizzato
A44	Superficie delle abitazioni occupate da persone residenti
E1	Edifici e complessi di edifici - Totale
E2	Edifici e complessi di edifici utilizzati
E3	Edifici ad uso abitativo
E4	Edifici e complessi di edifici (utilizzati) per alberghi, uffici, commercio e industria, comunicazioni e trasporti
E6	Edifici ad uso abitativo in muratura portante
E7	Edifici ad uso abitativo in calcestruzzo armato
E9	Edifici ad uso abitativo costruiti prima del 1919
E10	Edifici ad uso abitativo costruiti tra il 1919 e il 1945
E11	Edifici ad uso abitativo costruiti tra il 1946 e il 1961
E12	Edifici ad uso abitativo costruiti tra il 1962 e il 1971
E13	Edifici ad uso abitativo costruiti tra il 1972 e il 1981
E14	Edifici ad uso abitativo costruiti tra il 1982 e il 1991
E15	Edifici ad uso abitativo costruiti dopo il 1991
E16	Edifici ad uso abitativo con un piano
E17	Edifici ad uso abitativo con 2 piani
E18	Edifici ad uso abitativo con 3 piani
E19	Edifici ad uso abitativo con 4 piani o più
E20	Edifici ad uso abitativo con un interno
E21	Edifici ad uso abitativo con 2 interni
E22	Edifici ad uso abitativo da 3 a 10 interni
E23	Edifici ad uso abitativo con più di dieci interni
E24	Totale interni in edifici ad uso abitativo
PF1	Famiglie totale
PF2	Totale componenti delle famiglie
PF3	Famiglie 1 componente
PF4	Famiglie 2 componenti
PF5	Famiglie 3 componenti
PF6	Famiglie 4 componenti
PF7	Famiglie 5 componenti
PF8	Famiglie 6 e oltre componenti
PF9	Componenti delle famiglie residenti di 6 e oltre componenti
ST01	Stranieri residenti in Italia - Europa
ST02	Stranieri residenti in Italia - Africa
ST03	Stranieri residenti in Italia - America
ST04	Stranieri in Italia - Asia
ST05	Stranieri in Italia - Oceania
ST06	Apolidi residenti in Italia
ST07	Stranieri residenti in Italia - Totale

Figure 26: Italian Census data 3/3.

ANNEX V – NACE metadata

The NACE metadata classification is presented in the following:

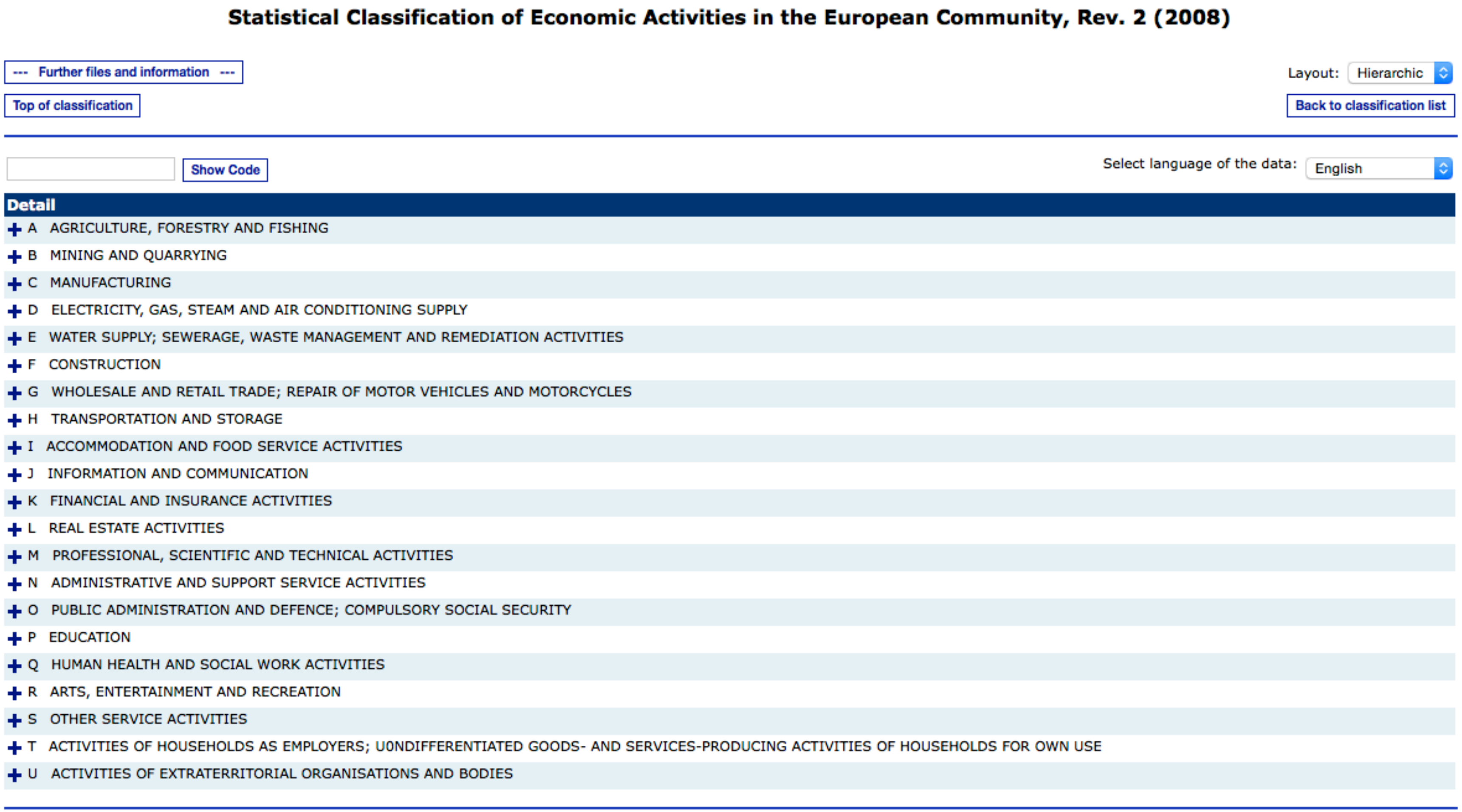

Figure 27: Statistical Classifications of Economic Activities in The European Community Rev. 2 (2008).

Each domain is further subdivided into further categories as indicated in the following:

METADATA

Statistical Classification of Economic Activities in the European Community, Rev. 2 (2008)

--- Further files and information --- Layout: Hierarchic

Top of classification Back to classification list

Show Code Select language of the data: English

Detail	
- 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 of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
+ 17	Manufacture of paper and paper products
+ 18	Printing and 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

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Figure 28: Statistical Classifications of Economic Activities in The European Community Rev. 2 (2008) - subsectors.