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# Strategies for improving Urban Resilience in Europe

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ABSTRACT:

The European Commission's Joint Research Centre has developed a number of methods and tools that contribute to better resilience of urban regions. Although the tools originally have not been conceived to improve resilience, they can make essential part of a resilience tool suite for national authorities, critical infrastructure owners and other relevant stakeholders. The tools are currently only partly or not connected to each other and the outputs of one cannot be used as input for the other since resilience assessment was not among their primary scope. This is a disadvantage of many available tools world-wide. One of the recommendations for the future is to develop such tools with the scope to fit suitable resilience frameworks that can ensure their connectivity and harmonized interaction.

Throughout its history the Joint Research Centre of the European Commission has dedicated a great part of its resources in risk reduction and the improvement of life in European cities. A number of tools and methods have been developed that fall under the umbrella of urban resilience. Although the developers didn't have in mind urban resilience plans originally, these tools and methods, in their whole, constitute important part of the knowledge and evidence that support the investment decisions for more resilience cities. In the next chapters these tools and methods will be presented.

## 1. THE GLOBAL HUMAN SETTLEMENT LAYER

Information on built-up area and population density are Essential Societal Variables that can be used to monitor and model human activities and the impact of hazards on society (Ehrlich et al. 2018). At a global scale, Earth Observation is one, if not the only, tool to provide up-to-date information on the status of global urbanization processes. In the framework of the EU's regional and urban policies, the JRC, with its global human settlement layer, GHSL, http://ghsl.jrc.ec.europa.eu/, aims at assessing human presence on the planet based on spatio-temporal evolution of the built –up surfaces and the populations living there. The data allow analyzing urbanization since 1975 at global, national and city level. The city level analysis relies on a new, harmonized definition of cities and settlements (Dijkstra et al. 2018). Applied to the GHSL data, the definition delineates urban centres, towns and suburbs around the world in a harmonized manner. According to this definition, there were around 10.000 cities with more than 50.000 inhabitants in the world in 2015 (Figure.1).

For each of the cities the JRC has collected a set of indicators including resilience relevant information such as exposure to flood, earthquake, storm surge and heatwaves or environmental conditions such as greenness, PM2.5 concentration and $CO_2$ emissions. This "urban centre" database can be found in: https://ghsl.jrc.ec.europa.eu/ucdb2018Overview.php

*Figure 1.Urban centres with more than 50.000 inhabitants in the year 2015 according the degree of urbanisation applied to the GHSL data.*

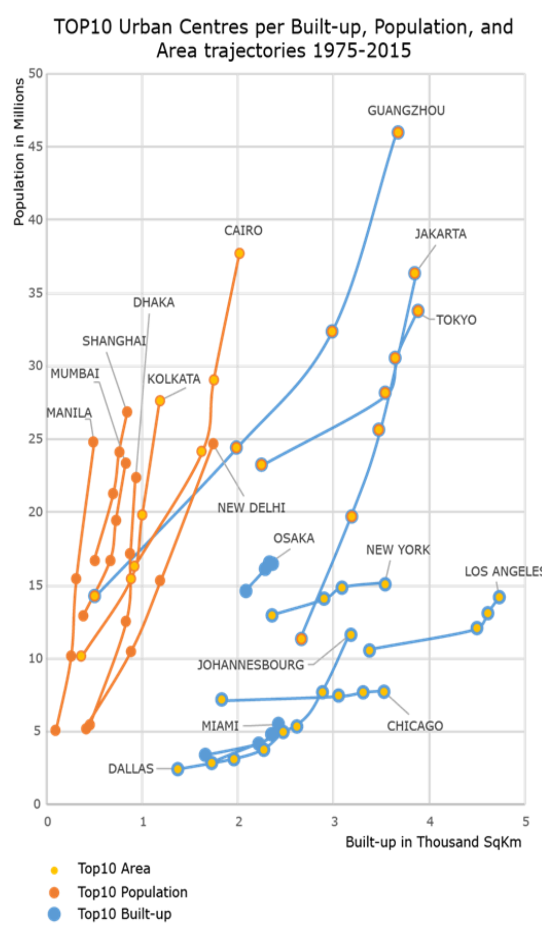


*Figure 2. Trajectories of built-up area and population from 1975 to 2015 for the 10 most populated and most built-up cities in the world.*

The multi-temporal dimension of the data set with the epochs centred around the years 1975, 1990, 2000 and 2015 allows analyzing the development trajectories of each city. Figure 2 shows the trajectories of the ten most populated cities and the ten cities with the largest built-up area. Apart from socio-economic divide (all top 10 population cities are in middle or low-income countries with the exception of Tokyo), there is a clear pattern observable. The most populated cities continue to grow in terms of population without significantly increasing the built-up area leaving the urban dwellers with always less space, while the large centres in high income countries continue to increase the built-up area often without significant increase in population. Such insights allow identification of hot spots that may require a policy intervention.

## 2. RISK DATA HUB

Disaster risk managers require technological support for complex forms of decision–making as they face challenges in linking data, information, systems and IT tools to take difficult decisions when facing a crisis. Given this context, the Disaster Risk Management Knowledge Centre Risk Data Hub (DRMKC-RDH https://drmkc.jrc.ec.europa.eu/) adopts a comprehensive framework of policies and guidelines, data sharing initiatives and spatial data infrastructures with the purpose of setting the bases for evidence-based Disaster Risk Management (DRM) at local, national, regional and EU-wide level.

The DRMKC-RDH is a new tool, still under development, based on a strong scientific partnership and developed in close collaboration with national authorities: the end-users. The main objective of DRMKC-RDH is to improve the access and share EU-wide curated risk data for fostering Disaster Risk Management (DRM). The effective development and implementation of well-informed Disaster Risk Reduction (DRR) actions will allow a more resilient future. The early adoption of mitigation and Nature-based solutions, as defined by IUCN (Int. Union for Conservation of Nature) will save lives.

JRC's Risk Data Hub will support the regular preparation of national risk management by member states' authorities. It combines human settlement layer data with hazard maps and physical inventories of assets (Figure 3). National governments would then be able to add their vulnerability assessments and coping capacity data to carry out their risk assessments and develop risk management strategies, as called by the Union of Civil Protection Mechanism (DECISION No 1313/2013/EU).

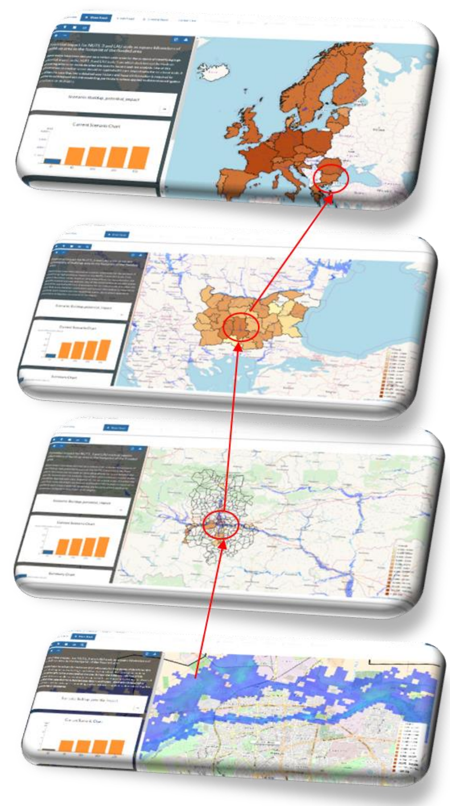

*Figure 3 Data4Policy - DRMKC Risk Data Hub: From local evidences to National and/or International Priorities.*

A well-structured and systematic collection of damage and loss data will allow us to better understand our future challenges by combining those data (the past) with the most advanced scientific models. Future projections of potential impacts including Climate Change scenarios can be compared with the past events and their trend to be better prepared.

Alternatively JRC's system INFORM (http://www.inform-index.org/) may provide the risk assessment based on composite indicators that include vulnerability considerations. INFORM is currently focused on developing countries, but the methodology is applicable also for developed countries based on other indicators.

## 3. THE BUILT ENVIRONMENT

### *3.1. Building standards*

UNISDR (United Nations Office for Disaster Risk Reduction) has developed a Disaster Resilience scoreboard for Cities (UNISDR 2017), which includes ten essentials for making cities resilient. The one with the title "pursue a resilient urban development" mentions the existence, application and updating of codes for the design of buildings against the hazards identified at local level as one important prerequisite for resilient building.

An illustrative example is the damage of residential buildings after the 2009 earthquake in L'Aquila, Italy. The buildings that were constructed before the 1974 seismic design code account for more than 40 % of the total number of damaged buildings, whereas those constructed after the 1996 code represent around 10 % of the total (Dolce and Manfredi 2015).

The EN Eurocodes are a series of 10 state-of-the-art European Standards based on the best available knowledge. They provide a common approach for the design of buildings and other civil engineering works together with geotechnical design; and the design, assessment and retrofitting of structures for earthquake resistance (https://eurocodes.jrc.ec.europa.eu). A project aiming to develop the second generation of the Eurocodes is currently underway.

### *3.2. European building stock*

Functional buildings and infrastructure systems are essential for communities to prosper. Therefore an inventory of the housing stock is important to identify regions of high risk and consequently prioritise interventions to reduce risk reduction and increase resilience.

(Palermo et al. 2018) developed a homogeneous database of the housing stock in 30 European countries (the 28 Member States of the European Union plus Norway and Switzerland) and performed a classification of the seismic vulnerability at a regional level. The results of the analyses highlight that in the seismic-prone regions of Europe, the majority of buildings were designed without provisions for earthquake resistance or with moderate-level seismic codes (Figure 4). Therefore, these buildings are vulnerable to earthquakes, may have a significant impact on a high percentage of the population and are in need of interventions that will reduce their vulnerability and consequently the risk of socio-economic losses.

In addition, the database confirms that most of the dwellings across Europe are located in old buildings that are reaching or have already exceeded their conventional service life. This impairs the resilience of urban areas as regards the impact of natural hazards on the built environment as well as the energy efficiency in the residential sector.

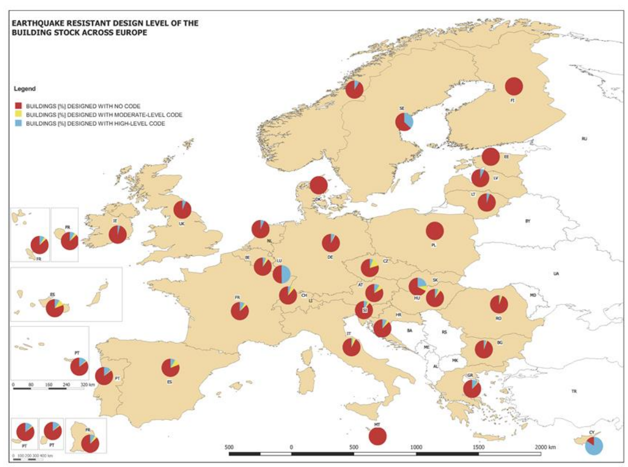


*Figure 4: Percentage of buildings designed without provisions for earthquake resistance (red), moderate level (yellow) and high-level (blue) seismic code (Palermo et al. 2018).*

### *3.3. Large-scale experimental research*

The JRC operates the ELSA Reaction Wall (https://ec.europa.eu/jrc/en/research-facility/elsa) which has unique dimensions and testing capabilities, and is used to test the vulnerability of buildings to earthquakes and other hazards.

Recent experimental research within the SERIES project (http://www.series.upatras.gr) studied new concepts for damage-tolerant buildings and methods to increase the resilience of existing buildings and bridges to earthquakes. In particular, the project studied the retrofit of existing reinforced concrete (RC) viaducts with friction pendulum systems (Paolacci et al. 2014), braced frames with removable dissipative links and re-centering capability to reduce the repair costs and downtime of a structure hit by an earthquake (Sabau et al. 2014) and retrofitting of multi-story multi-bay RC frame buildings by converting selected bays into new walls through RC infilling (Poljanšek et al. 2013).

The current experimental activity in the framework of the Horizon 2020 SERA project (www.sera-eu.org) aims to study i) the response of flat slab RC structures under combined gravity and lateral loads, and ii) the behavior of steel frame structures and fire protection systems in the case of fire following an earthquake.

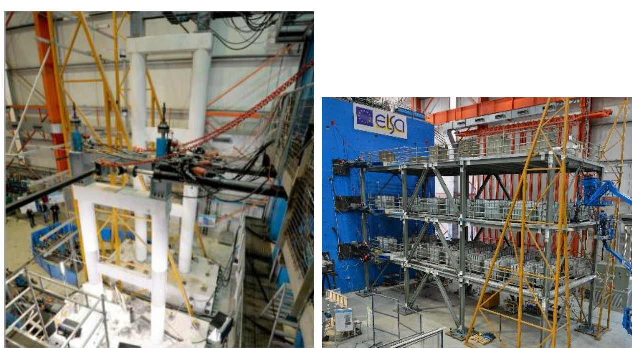

*Figure 5: Experimental testing of viaduct retrofitted with friction pendulum isolation devices (left) and braced frame with dissipative links (right).*

## 4. UTILITY RECOVERY TIMES AS RECOVERY INDICATOR

In the framework of the JRC-BRI (Building Research Institute of Japan) collaboration agreement, JRC performed a field mission in the Kumamoto Prefecture after the earthquakes that struck it in 2016 between April 14th and 16th. During the post-earthquake survey, data concerning the operations of the Civil Protection Mechanism and about the recovery of business and facilities were collected, along with the analysis and assessment of some collapsed and damaged buildings.

The collected information was improved subsequently thanks to the continuous sharing of data with Japanese counterparts. Data on disruptions to private buildings are available of the following public utilities:

- Electricity (n. of interrupted users / day);
- Natural gas (n. of interrupted dwellings / day);
- Drinking water (n. of interrupted users / day);
- Sewerage systems (Total extension (km) and Extension of damage (km)).

A calibration of the recovery functions of public utilities in the Kumamoto Prefecture is possible using the collected information.

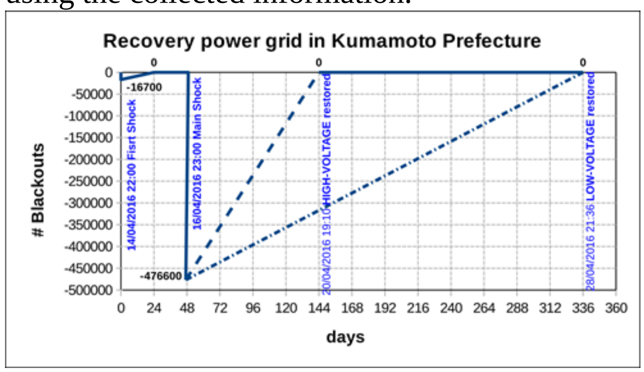


*Figure 6 Recovery of power grid in the Kumamoto Prefecture.*

In addition, the interaction between recovery operations and new catastrophic events may be analyzed using the seismic sequence that hit Kumamoto, with seven shocks in 36 hours, two with intensity 7 (the highest according to the Japanese meteorological agency).

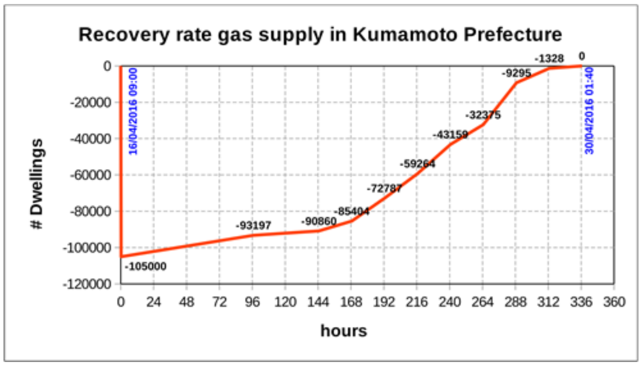


*Figure 7 Recovery of gas supply in the Kumamoto Prefecture*

## 5. UNDERSTANDING INTERDEPENDENCIES

Critical infrastructure systems are tightly interconnected and disruption of one infrastructure may have far reaching effects across technological systems, and jurisdictions affecting large areas and several countries. Risk assessments deal with risks at sectoral level and rarely take into account the interactions between sectors of infrastructures and systems. Building resilience in each critical infrastructure sector as well as across sectors calls for an approach that expands beyond risk assessment and requires understanding the big picture of cascade effects and impact on the society and the economy.

Research has focused on developing detailed low level models which aim at the interactions between specific sectors relying on the underlying physics and flow models. In the work of Ouyang, Min (2014) one can find an excellent overview of the various such models.

Despite the fact that the level of uncertainty of these models is rather reduced this is taking place at the expense of usability by non-experts. This prohibits policy makers from using such modelling tools.

Other approaches are implementing methods that do not rely on flow models or on the underlying physics and employ agent based models or system dynamics models as a more generic approach for modelling interde-pendencies and assessing the impact across sectors. The work of Casalicchio et al. (2010) is such an example although several more exist.

Another critical issue is the access to the necessary datasets. The main obstacle is the willingness of the private sector to share relevant data. The perception of operators is that there are no incentives or direct/indirect benefits for sharing such data. At times operators may understand well how they depend on other infrastructures they are not always aware of the number of infrastructures and sectors that depend upon them. As a consequence the analysis of interdependencies needs to be performed by authorities while the data have to be collected by the private sector. This makes interdependencies analysis more a governance/cooperation issue rather than a technical issue.

There are three main challenges to be addressed in order to foster the development of interdependencies analysis performed by the authorities. The first is the lack of simplified yet robust models which can be used by policy makers, the second is the need for simplified datasets which can be easily retrieved without excessive effort from the authorities or from the private sector and third the establishment of a continuous collaboration between these two categories of stakeholders in order to share information, analysis output and design contingency plans.

JRC has developed the Geospatial Risk and Resilience Assessment Platform - GRRASP [1] with the main objective to provide an analysis tool to improve risk and resilience assessment at local, regional, national and international scale. One of the models that are introduced in GRRASP is focused on assessing interdependencies between infrastructures using a service based approach, i.e. sector agnostic. The modelling approach that has been implemented in GRRASP is based on the work

[1] GRRASP is available at: https://ec.europa.eu/jrc/en/grrasp

of Trucco et al. (2012). The main aspect of this work is the notion of nodes which represent functional entities that provide services to other nodes or to final clients (e.g. citizens). These functional entities are associated to geographical attributes at different levels of granularity (depending on the level of analysis). For example at local level, each substation of the power network can be considered as a node (functional entity) but at national level several substations can be clustered and be considered as one node.

Each node's functionality is described by 3 different types of data. 1) Data related to the internal function of the node and its intrinsic capability to provide services as well as the level of service demand for this particular node at any given moment (time profile) 2) data related to the level of its dependency to other nodes and 3) data related to the shift of demand by end users between infrastructures that provide similar services.

The analysis of a what-if scenario involves the injection of a disruption in one or more infrastructures and given the level of the interdependencies mapping it is possible to obtain a detailed assessment of the cascade effects across the various nodes. The output of the analysis is a time profile of the level of inoperability of a node (in fact the level of service demand that is not served) in the form shown in figure 8.

This analysis output can give a quick overview of the cascade effects across the various infrastructures, their level of inoperability and the level of service demand that cannot be served by each of the nodes included in the analysis. In that way the policy makers can identify areas where resilience measures have to be enhanced in order to reassure that nodes of high priority (e.g. hospitals) continue to operate without major disruptions.


*Figure 8 Output of interdependencies analysis in GRRASP*

## 6. THE POWER GRID

Quick recovery of the power grid is essential for the well-being of the citizens during and after a disaster. A recent JRC study, which looked into possible constraints of power grid recovery after earthquakes, floods and space weather events (Karagiannis et al., 2017) concludes that different natural hazards affect the power grid in different ways which is reflected in the time it takes the power grid to recover. Using forensic analysis of past events, the study found that on average it took 1 to 4 days to restore power supply in case of earthquakes while power recovery after floods was more protracted (1 day to 3 weeks, with restoration times of up to 5 weeks in case of floods associated with storms). Space weather impacts can result in system-wide impact. In case of limited damage the power restoration time is 24 hours, however, repairs of damaged equipment may take up to several months. The study also identified factors that aggravate power supply recovery after disaster which include the resilience of electric power utilities and the disruption of other critical infrastructure (mainly transportation and telecommunications), either as a direct result of the natural event or because of dependencies with the power grid.

The study recommends that given the grids' interconnectivities among EU countries, risk assessment should be carried out across EU countries and policies with relevance to the grid, with a consistent set of scenarios. Along with hardening components and buildings and with stockpiling of replacement items, the development, implementation and testing of outage management plans is essential.

Trying to understand the consequences of natural hazard impacts on hazardous industry and critical infrastructure, the JRC has developed its RAPID-N tool for rapid Natech risk assessment and mapping (Girgin and Krausmann, 2013). Application of RAPID-N allows authorities to anticipate Natech risks at industry and critical infrastructure in their specific local or regional context by helping them with:

- Identification of Natech risk hotspots where additional protection might be needed;
- Land-use and emergency planning for risk prevention and better preparedness;
- Rapid Natech damage and consequence assessment to inform emergency-response decisions before dispatching rescue teams or to alert the population;
- Screening for potential risks due to cascading effects from a Natech accident.

RAPID-N is available for free via prior user registration and authorization at [http://rapidn.jrc.ec.europa.eu](http://rapidn.jrc.ec.europa.eu) . It is based on four self-contained but interconnected modules, each of which performs a specific task in the assessment process. The output of the RAPID-N assessment is a risk summary report that features all parameters used in the assessment and an interactive risk map showing the scenario-specific impact areas. Figure 9 shows a screenshot of a RAPID-N regional study highlighting the risk of suffering second-degree burns due to earthquake impact at hazardous facilities. Since the user can choose the impact criteria, RAPID-N can determine the likelihood and severity of human impacts as well as of damage to neighboring structures (e.g. power plants, ports, etc.) alike. This helps to understand the risks of cascading effects that might hamper a speedy recovery after a natural event.damage severity and probability estimation, and risk assessment) in one tool.

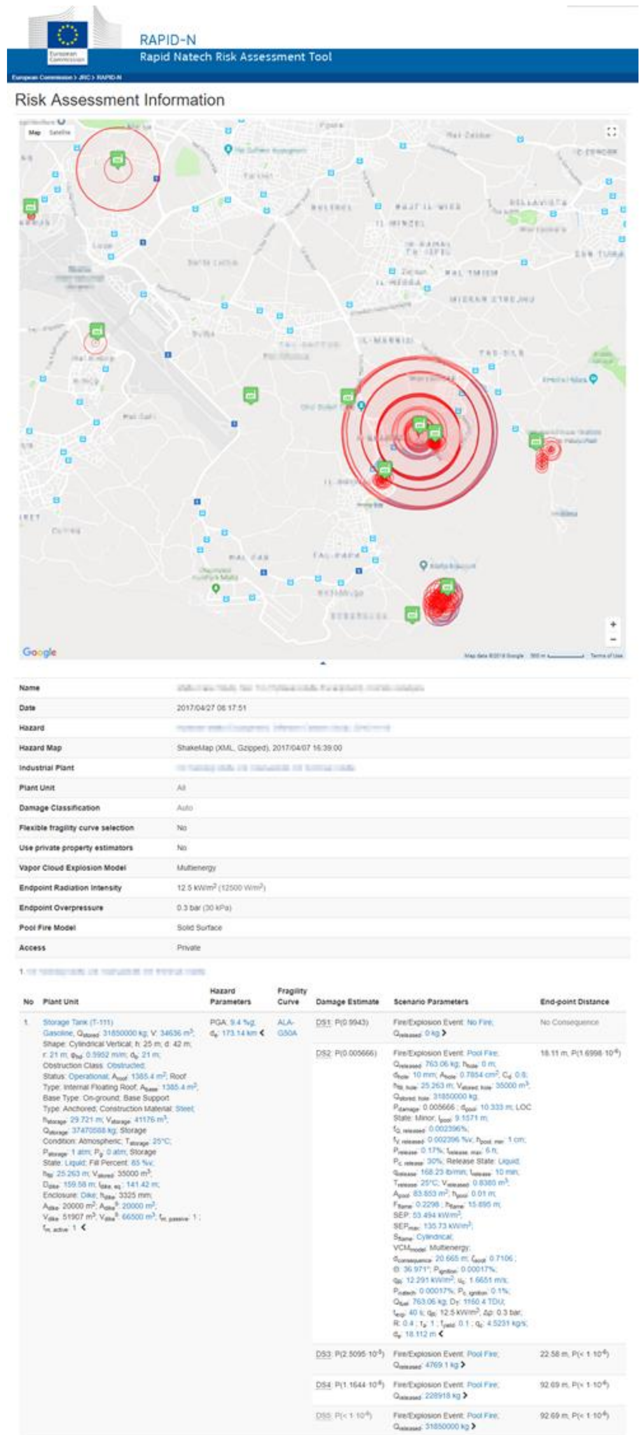


*Figure 9 RAPID-N system allows users to assess and map Natech risks locally or regionally*

## 7. MANAGING RESILIENCE FOR UTILITIES

The resilience of utilities depends on their ability to effectively manage the risks to their operations. Utilities gradually shift focus from protecting assets from hazards to being able to continuously provide a minimum level of essential services to the public. JRC has worked in close collaboration with them and, through the EU-funded H2020 IMPROVER project, has proposed guidelines on critical infrastructure resilience for utilities and for policy makers (Theocharidou et al., 2018). Infrastructure resilience refers to the technological resilience of systems or assets, and the organizational resilience of the operator, but also considers the characteristics and resilience of its social context.

For the assessment of the technological and organisational dimensions, IMPROVER has developed (Lange et al., 2018):

- CIRI – the critical infrastructure resilience index and the accompanying methodology for implementation, which is self-assessment, indicator-based tool.
- ITRA – the IMPROVER technological resilience analysis methodology, which accounts for different time scales in the aftermath of an incident as well as the recovery analysis for utilities.
- IORA – the IMPROVER organisational resilience analysis methodology, which is a narrative based methodology for analysing organisational resilience, based on indicators.

On the societal dimension, resilience could be measured based on 6 dimensions, called capitals, which make up the basis for the indicators within the IMPROVER Societal Resilience Analysis (ISRA) methodology. These capitals contribute to the coping, adaptive or transformative capacity of a community faced with crises or with change over time. While the resilience of utilities is considered as the physical capital, the methodology also considers the institutional, human, social, economic and natural capitals. ISRA accounts for 63 societal resilience indicators.

IMPROVER and JRC have proposed guidelines for policy makers, since the improved resilience of critical infrastructures can enhance resilience in the Member States and in Europe.

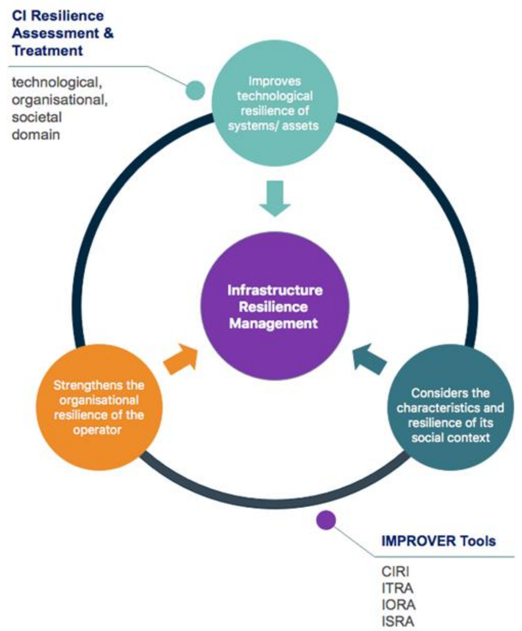


*Figure 10 IMPROVER resilience approach for utilities*

Utilities contribute to managing disaster risk at local, regional or national level, in the face of all hazards. A Resilience Strategy should also aim at the continuous provision of essential services by utilities to the public, to businesses, to governments communities, to other sectors. A resilience-based approach is a shared responsibility and an outcome of partnership between governments, communities, infrastructures, businesses and individuals. The key principles of the resilience guidelines are presented in the figure 11 (Theocharidou et al., 2018).

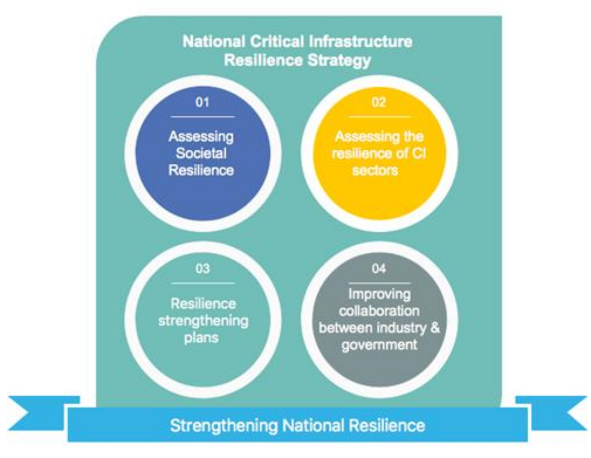


*Figure 11 IMPROVER resilience guidelines*

## 8. CONCLUSIONS

A number of tools and methods have been developed to cope with the various aspects of resilience. These tools and methods operate independently from each other and are currently not introduced into the various resilience frameworks. The next step would be to further develop these tools and methods so as to make them work together in a coordinated way and by matching inputs with outputs to be able to plan and assess resilience in a holistic way. In this way they can be inserted in the resilience frameworks and become useful for operators and authorities.

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