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RESCCUE

RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

D5.1 MULTISECTORIAL RESILIENCE STRATEGIES FRAMEWORK AND STRATEGIES DATABASE DEVELOPMENT

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DATE	VERSION	AUTHOR	COMMENTS
	v0	Martínez-Gomariz, Eduardo	In this "zero version" most of CETaqua's contribution is included; no reviews of the contents have been conducted though. Therefore, I suggest that you read it and feel free to share your comments or suggestions if any. You'll miss the two last sections (CETaqua's contribution as well),

			regarding the database elaboration and of course the conclusions, which will be written after collecting all your contributions.
	v1	Martínez-Gomariz, Eduardo	It includes IREC's contribution regarding power sector.
	v2	Martínez-Gomariz, Eduardo	It includes AQUATEC's contribution
	v3	Martínez-Gomariz, Eduardo	It includes additional AQUATE's contributions
	v4	Martínez-Gomariz, Eduardo	It includes BCC's contribution
20 October 2017	v5	Martínez-Gomariz, Eduardo	It includes some LNEC's contributions
23 November 2017	v6	Martínez-Gomariz, Eduardo	It includes more LNEC's contributions
30 November 2017	v7	Martínez-Gomariz, Eduardo	Reviewed version
19 March 2018	v8	Martínez-Gomariz, Eduardo	It includes EU reviews
02 November 2018	V9	Martínez-Gomariz, Eduardo	It includes second EU reviews

1. **Changes with respect to the DoA**
   None

2. **Dissemination and uptake**
   Public (PU). The report is fully open and will be distributed through the web

3. **Short Summary of results (<250 words)**
   Deliverable D5.1 – "Multisectorial resilience strategies framework and strategies database development" provides a detailed framework, based on three key variables (estimated cost, co-benefits, and recovery time reduction) related to adaptation strategies in order to make decisions to select them in an effective manner.
   Moreover, a database of adaptation measures has been performed, by providing a comprehensive characterization based on a literature review and the partners suggestions (with the remarkable contribution of city councils).

4. **Evidence of accomplishment**
   A web-based application has been developed (https://resccue.herokuapp.com/) also in order to facilitate the visualization and creation of measures and strategies.

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Executive Summary

Deliverable D5.1 develops the two first tasks of fifth Work Package (following WP5) dealing with the resilience and adaptation strategies ready for market uptake. Specifically, this document deals with the **development of a framework to promote resilience strategies and the creation of a measures database**.

While an adaptation **measure** is a specific intervention to address a specific climate hazard, an adaptation **strategy** is a collection of measures linked to specific hazards and their impacts. Therefore, after the diagnosis of current situation (i.e. problem characterization or gaps assessment) in the cities, resilience or adaptation strategies, which are formed by adaptation measures, will be proposed.

In order to consider the city **recovery time** reduction, when defining an adaptation measure, a matrix which relates urban services with hazards has been proposed to be linked to each adaptation measure. It defines how effective the application of a measure is for certain services affected by hazards, but also how it is jeopardizing the recovery capacity of another by varying the . Consequently, the global resilience level of the city could decrease if it occurs.

The selected variable for this matrix has been the percentage of variation of the time a specific urban service is expected to be down. The "what if matrix" in the Hazur® platform establishes the period of time (down time) during which either a service or an infrastructure becomes inoperable or is not performing its proper function due to a certain impact (e.g. Flood, heat wave, drought or sea level rise). Therefore, the proposed matrix is expected to act on the "what if matrix", in order to modify the initial down times with new values which lead to obtain a reduction on the city recovery time. This matrix has been named as Variation of Recovery Time matrix (VRT).

The complexity of the interrelation among urban services leads to consider aspects such as cascade failure effects, which is comprehensively treated thanks to the use of the software-based solution Hazur®. In the RESCCUE project the initial resilience state for each research site will be established thanks to the resilience assessment in each city by means of Hazur®. Therefore, in case of effective adaptation strategies the city resilience should increase, hence, a post-strategies city resilience state will also be assessed through Hazur®.

Another essential information to be provided to each adaptation measure are the possible **co-benefits** that may occur when implementing a specific measure. A co-benefit resulting from an adaptation measure/strategy means that it is an additional benefit, different from the one the measure/strategy is targeted on, and which is not necessarily 'climate related'. A list of co-benefits, grouped in three different types (i.e. economic, social and environmental), has been proposed herein. Therefore, within the required information for each measure, the importance of each listed co-benefit will be considered by establishing a weight from zero (no effect) to ten (totally beneficial).

Finally, another important reason for a decision maker for implement a specific adaptation strategy is its cost, not only the initial investment but also the cost burden resulting from its maintenance. Therefore, their **estimated cost** is considered a key variable to decision making, which will be related to each proposed adaptation strategy as an important variable in order to make decisions to select them. Moreover, in a second stage, the estimated cost will be

taken into account when a cost benefit analysis (CBA) will allow to prioritize the selected strategies.

Although, in order to increase the resilience of a city, after a previous initial city gaps assessment, adaptation (or resilience) strategies have to be defined, the creation of a database of adaptation measures is essential as starting information. The required information (in addition to related co-benefits and VRT) to properly characterize adaptation measures has been proposed based on the conducted literature review and the suggestions of the city councils (Barcelona, Lisbon and Bristol) according to their needs. This has made it possible to gather 94 adaptation measures within a database. Furthermore, a web-based platform has been developed (access: https://resccue.herokuapp.com/login email: user@resccue.com; password: User1234) in order to create resilience strategies based on the stored (and future new ones if required) adaptation measures. The adaptation strategies already planned by the three City Councils involved in this project, have already been created through the web-based platform. However, some other adaptation strategies will arise along the project lifetime based on its outcomes.

1 Introduction and RESCCUE general framework

1.1 Overview

This document (D5.1) develops a framework to promote resilience strategies and the creation of a measures database, and it has been developed in the wide context of the RESCCUE Project. The Project deals with climate change in urban areas, so that, with the resilience and potential impacts of extreme events on urban services, like transports, energy production, and water and energy distribution. The project will provide a framework enabling city resilience assessment, planning and management. RESCCUE assumes a significant importance in increasing urban resilience to a wide range of challenges, which can have physical, economic or social origin, being the natural ones, the threats of main concern in RESCCUE. In particular, this objective has to be achieved by implementing new tools and models, suitable for different kinds of city (Lisbon, Barcelona and Bristol), characterized by several climate conditions and pressures. One of the most important contributions of the Project is the analysis of the relations among the several urban services and the impacts that climate change will generate on each one, giving particular relevance to effects of a failure in one sector and its consequences, in terms of cascade effects, also on the other ones.

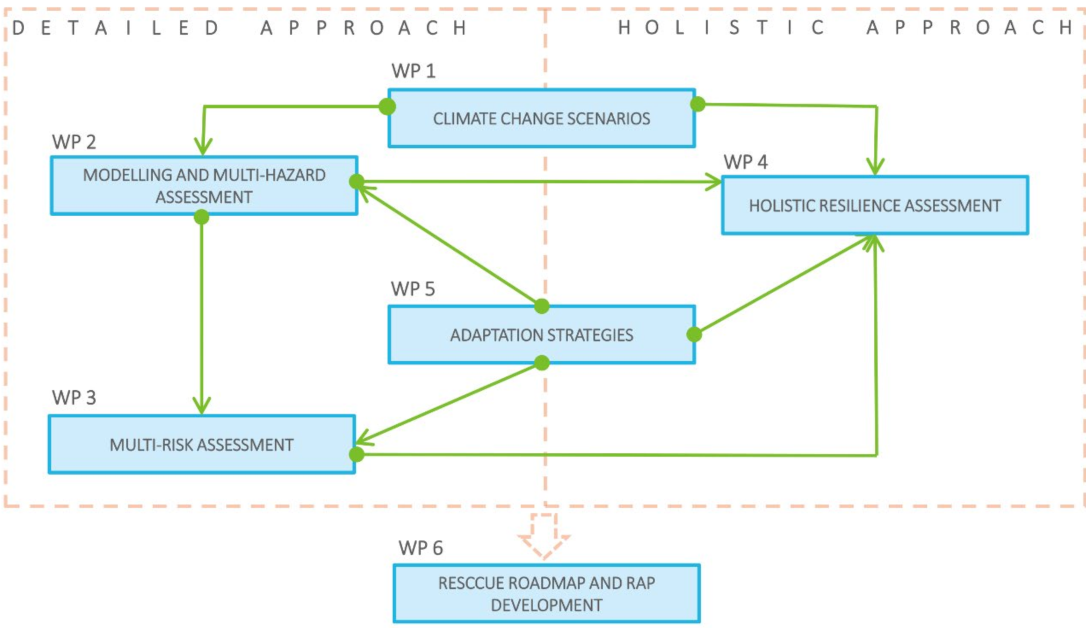


Figure 1. Summary of RESCCUE framework

The detailed knowledge of the behaviour of our urban systems during extreme climate events has been used to characterize the sites and analyse each urban services with special focus on their potential link with extreme climate phenomena.

On the other hand, the analysis of the behaviour and the response of strategic services and critical infrastructures with respect to specific pressures and drivers related to climate change has to be conducted through detailed models and software tools. The outputs of these sectorial models will be used to assess hazard, vulnerability and risk levels related to the pressures/drivers for current and future scenarios where a large set of measures and strategies will be simulated and evaluated in terms of impacts reduction. Afterwards, as a second step, the urban services interdependencies and the cascade effects due to failures or extreme climate events can be studied.

This second step in RESCCUE is treated by two different approaches characterized by a different level of detail:

1. Detailed approach: Advanced models and tools to describe specific cascading effects produced by extreme climate events on several urban services are developed. Then, the analysis of certain impact events could be achieved via the use of loosely coupled models and tools (integrated models). In this case, **adaptation strategies and measures will be proposed and prioritized on the basis of hazard and risk reduction but, also, through multi-criteria analysis providing an overview of other kinds of co-benefits**
2. Holistic approach: using the resilience assessment tool (HAZUR), the relations and the cascading effects among the different urban services can be analysed. In this case, **adaptation measures and strategies will be focused on the recovery of the normal functioning of the city and, specifically, of its strategic urban services and infrastructures. This concept will be expressed by the concept of recovery time and the efficiency of the measures and strategies, in terms of decrease of recovery**.

1.2 Considered hazards for the different sites

Hazards are mainly due to changes in significant climate variables because of climate change. In this section, hazards that jeopardise the cities analysed within this project are briefly described in Table 1.

Table 1. Summary of Hazards for the different sites

Site	Hazards
Lisbon	Heat wave, high temperature, cold wave, low temperature, sea level rise, storm surge, urban flooding, drought, CSO, windstorm, thunderstorm and hail
Barcelona	Rain storm, heat wave, drought, forest fire, flash/surface flood, river flood, coastal flood, storm surge and salt water intrusion and severe wind
Bristol	Heat wave, sea level rise, urban flooding, drought, CSOs, windstorm and snow

As can be noted, there are hazards that characterize all the RESCCUE research sites and others that affect just one or some of them. In the following lines, the climate variables responsible for all the identified hazards are reported as well as the natural variables that are not related to climate.

Rain storm, urban flooding, flash/surface flood, river flood, coastal flood, CSO, snow, hail and drought are all due to rain climate variable, windstorm is due to wind climate variable, heat wave, sea level rise and extreme hot temperature are both due to extreme temperature climate variable, storm surge is due to wave action climate variable, forest fire is due to wild fire variable, salt water intrusion is due to chemical change.

1.3 Sectors and services description for the different sites

This section offers a brief description of the most relevant sectors and services related to each research site considered within this project (Lisbon, Barcelona and Bristol). Water Cycle, Power, Mobility and Waste are the sectors mainly treated in this project through detailed analysis of their behaviour during crisis or extreme climate events; however the services related to each sector are different among sites according to their importance. Table 2 shows a list of services related to their sectors.

Table 2. Sectors and related services

Water Cycle	Power	Mobility	Waste
Urban drainage	Power generation	High speed roads	Waste collection
Water storage	Power distribution	Streets	Waste treatment
Water distribution	Power transportation	Subway	
Water treatment	Electrical mobility network	Railways/Trains	
Water sourcing and transportation	Public lighting and traffic light	Tram	
Wastewater treatment		Bus	
Treated wastewater reuse		Port	
Green infrastructure		Airport	

Some relevant services relate to the **water cycle**. Lisbon sewer system includes combined, separate and partially separate sewers that are characterized by different dimensions, materials and age. Furthermore, the final pipes of the sewer network in Lisbon are affected by the sea level because they are located in the lowest part of the City. For this reason, their capacity results quite reduced. Totally, Lisbon sewer system has a length of 1,400 Km.

Water abstraction is mainly from the Castelo do Bode reservoir, whose dam is located in the Tagus river basin and owned by EDP Group. The water treatment is carried out at Asseiceira Water Treatment Plant, while water distribution is conducted by EPAL, which provides any citizen with 650 million litres of drinking water per day. In order to do that, 2,100 Km of water mains, 43 pumping stations, 24 water tanks, 14 service reservoirs and 80 thousand service connections are employed.

In Lisbon, EDP Distribuição manages the power sector. EDP group is the largest producer, distributor and supplier of electricity in Portugal.

The **transport infrastructure** in Lisbon includes 235 bridges and other structures as tunnels and viaducts in the road and rail network. Furthermore, the city has a number of terminals and other areas that serve as interface between several ways of transportation, both public and private. Lisbon also has an innovative plan aiming to introduce and increase the use of electrical vehicles. The existing rail network is managed by several organizations:

Infrastructures of Portugal S.A., Lisbon's Transports, Lisbon's Metropolitan (ML) and Companhia Carris de Ferro de Lisboa.

Finally, CML manages the **waste sector** in Lisbon, which handles the collection and the transport of undifferentiated and recyclable waste as well as the pest control and the population of pigeons.

Regarding **water sector** of Barcelona site, drinking water supply is obtained through groundwater sources and the Ter-Llobregat system joint to adequate treatment undertaken in the Sant Joan Despí Drinking Water Treatment Plant (SJD DWTP). Water from the SJD DWTP can be mixed also with drinking water coming from different sources and other large systems like Cardedeu DWTP, Estrella wells and Besòs DWTP. Any citizen in Barcelona is nowadays provided with 100 litres per day, therefore it is one of the lowest water consumption rate in Europe. Water distribution in Barcelona is conducted thanks to a network of 4,574 Km of pipes, 65 pumping stations and 72 water tanks. Moreover, the network has a telecontrol system available.

The urban drainage system in Barcelona is combined, with the 55% of the sewer system accessible by maintenance personnel. It is characterized by 1,556 Km, 15 storm tanks, 44 gates, 15 pumping stations, 41 combined sewer overflows and 31 rainwater sewer overflows.

Concerning waste water treatment in Barcelona, it is carried out through two waste water treatment plants. The first one is known as El Prat de Llobregat WWT, which presents treatment capacity of 420,000 cubic meters per day. The second WWTP is the Besòs waste water treatment plant and it is the largest one in Barcelona area, with a capacity of 525,000 cubic meters per day.

Barcelona **power sector** relies on several sub-domains, which are: hydroelectric, wind electricity and solar electricity.

The **transportation sector** in Barcelona involves many new areas created in order to incentivize pedestrians and mobility on foot. Journeys on foot and on bicycle present very positive rates (49.29%). The city has available a bicycles public service called "Bicing". Also public buses, metro and trains are widely used by citizens (50.75%) thanks to their reliability and the high number of stations.

The telecommunication service in Barcelona is mainly managed by Telefónica. Its network provides users with telecommunication services through 6,500 buildings and 10,800 other locations as fuse boxes and underground enclosures.

Finally, regarding **waste sector** in Barcelona, waste is collected differently depending on its origin. Household waste collection is conducted by several companies contracted by the City Council and selective collection is incentivized. Commercial waste comes from shops, economic activities and suitable industries. This waste can be collected using the municipal waste system or with the Catalan Waste Agency. Furniture and big pieces of junk are collected freely in assigned days. There are also many green points in order to collect polluting waste that cannot be included in any selective collection.

On the other hand, regarding **water cycle** in Bristol, water abstraction is made from the River Severn and treated in order to obtain half of current water available. A further 10-15% of water is instead abstracted from groundwater sources. In cases of demand peaks that exceed the river and groundwater sources, the City uses surface water reservoirs. The Chew Valley

Reservoir had been built in order to get more drinking water. This lake is owned by Bristol Water and its capacity is 20 thousand million litres.

Regarding the urban drainage, Bristol is characterized by separate and combined sewer systems. Bristol sewer system is suitable to cope with prolonged rainfall events, but unfortunately the network is not efficient in case of short and intense rainfall because of its limited capacity. Therefore, surcharging and flooding occur in this case. Wessex Water is responsible for managing the sewer network and the associated flood risk from this source in Bristol.

Waste water treatment is done mainly at Avonmouth, in a big waste water treatment centre that can work with 300 million litres of sewage per day.

Regarding the **power sector** in Bristol, it shows three main sub-domains that are: solar energy, wind energy and biomass. The energy provision is usually conducted by private companies. One of the main electricity provider is Western Power Distribution, which owes 186 electrical substations in the Bristol region. About natural gas, most of it is provided by British Gas, even though there many other companies and providers.

About **transportation sector**, Bristol presents many connections and motorways, managed by the Highways Authority. The major roads in Bristol are 18 and the streets are 6,114. Then, the City shows a rail network that connects to all major cities and also a dock widely used for industry and tourism cruises. The airport connects to European and no-European destinations.

In the end, the last one considered in Bristol is **waste sector**. In the City, energy is created from waste thanks to the opening of a Mechanical Biological Treatment plant in Avonmouth, which produces fuel. In the recent periods, furthermore, recycling rate has been 50% because waste collection and waste treatment services have been introduced.

Some other sectors, such as emergency, health, environment, social and energy will be considered also when defining interdependencies in Hazur®, and therefore they will be included in the measures and strategies database.

1.4 Known vulnerabilities: Hazards to sectors

After knowing the main sectors and services taken into account within the RESCCUE project, together with hazards jeopardising all three cities considered within this project (Lisbon, Barcelona and Bristol), this section describes vulnerabilities of these urban services to the studied hazards. The behaviour of some of the later considered services facing extreme climate events for current and future scenarios will be analysed comprehensively as well as their impacts. Others will be considered to study their relation with other services and their cascading effects in case of crisis events in a more general way through the Hazur® platform.

The affected urban sectors in ***Lisbon*** are: power, telecommunication, water cycle, waste, and transport. Although the vulnerabilities of other urban elements such as green infrastructure and urban equipment are analysed too.

In respect of **power sector**, hazards that can provoke failure and disruption are: heat wave, sea level rise, urban flooding and windstorm. In particular, jeopardised services are: electric transportation and electric distribution because substations, overhead lines and underground cables can be damaged. The main consequences of disruption in this sector may be: damage, collapse and interruption of energy supply, but also failures concerning electromechanical and control systems due to water supply cascading effects. Failures in power sector are very likely to provoke also disruption in the urban drainage sector because of failures of pumping and control systems.

For urban **water cycle sector**, jeopardised services are: water supply, urban drainage and waste water treatment. Water supply is likely to have a failure in water distribution subsystem, and in particular to the distribution network, because of its vulnerability to drought. If these events occur, the main consequences are insufficient availability and limitation in supply. About urban drainage service, failure affects sewers systems, so sewer networks and pump stations. In particular, these critical elements are vulnerable to sea level rise, urban flooding and CSOs.

The main consequences are: limited conveyance capacity and high street water level and velocity. There are many cascading effects as road and rail traffic disturbance, flooding of underground infrastructures, solid waste, untreated discharges, pollution of receiving water bodies, high salinity degrading mechanical equipment, and excessive inflow. The last affected service of urban water cycle sector is the waste water treatment. Waste water treatment plants are vulnerable to sea level rise, urban flooding and CSOs. The main damages caused by these events on waste water treatment plants are entry of salty water into the system, potential corrosion of important infrastructures, lower treatment and excessive inflow.

Regarding **waste sector** in Lisbon, the only affected service is cleaning. Critical elements, subjected to damage and disruption, are solid waste containers. These elements are vulnerable to urban flooding and windstorm. The main direct consequences of these events are: damage, displacement and overturn of containers, but there are also several cascading effects on urban drainage like obstruction of components and surface flows.

The **transport sector** is jeopardised by hazards because roadways, rail and metro are vulnerable to sea level rise, urban flooding and windstorm. Main critical elements are: roadways, local roads, traffic signals, and rail and metro networks. Flooding and windstorm can provoke disruption of public and private transportation while wind can generate failures of traffic control systems.

On the other hand, **green infrastructures**, mainly trees, are elements which are also jeopardised. They are vulnerable to windstorm, which is often responsible for their collapse. There are many possible cascading effects, among which: obstruction of components, damage to equipment, damage to lines, road and rail traffic disturbance and interruptions.

Lastly, **urban equipment** are other jeopardised elements in Lisbon city which should be considered also and is vulnerable to urban flooding and windstorm. Main consequences are expressed mostly in terms of cascading effects, like damage of urban drainage due to obstruction of components, damages to equipment and lines, road and rail traffic interruptions.

In ***Barcelona*** city, vulnerable urban sectors are: power, telecommunication, urban water cycle, waste, mobility and other elements such as green infrastructure. About **power sector**, vulnerable services are: power generation, power transmission and power distribution. In particular, critical elements are: large power plants, distributed power plants, high-voltage overhead lines, high-voltage buried cables, conventional electric substations, underground power substations, compacted substations, gas isolated substations, substations, medium voltage overhead grid, medium voltage buried grid, transformation centres. These elements are vulnerable to: rain storm, severe wind, forest fire, flash/surface flood, river flood, coastal flood, storm surge and salt water intrusion. For Barcelona site, energy service is the most critical because the other urban services rely on it, therefore a disruption in energy supply may affect telecommunication, urban water cycle, waste collection, waste treatment and transportation systems.

About urban **water cycle sector**, vulnerable sectors are: water supply, urban drainage and waste water treatment. The affected subsystems are: water abstraction, water treatment and storage, water distribution and sewers system. In particular, critical elements are: catchments well, drinking water treatment plants, desalination plants, drinking water network, water storage tanks, groundwater network, SUDS, sewer network, pumping stations, interceptors, gates, weirs, waste water treatment plant, saline intrusion barrier network and saline intrusion barrier wells. They are vulnerable to: rain storm, severe wind, drought, forest fire, flash/surface flood, river flood, coastal flood and salt water intrusion.

Waste sector is also a vulnerable in Barcelona. In particular, affected subsystems are: Solid Urban Waste Collection (SUW), SUW treatment and cleaning. Critical elements are: treatment plants, cleaning centres/vehicle storage, pneumatic waste collection plants. They are vulnerable to: rain storm, severe wind, forest fire, flash/surface flood, river flood, coastal flood and storm surge. A failure in this sector may have heavy consequences on citizens' health, economic activity and image of the City. Furthermore, a significant cascading effect of a disruption of waste service is the failure of the drainage system because of obstructions caused by the waste.

Regarding **mobility sector**, it is vulnerable to: rain storm, severe wind, forest fire, flash/surface flood, river flood, coastal flood and storm surge. Mobility services subjected to the previous vulnerabilities are mainly roadways, rail, metro, infrastructure for river and sea transportation. In particular, critical elements are: structuring basic network, secondary network, local basic network, surface and underground railway network, surface and underground railway stations. The main consequences of failure of mobility services are given by disorder in mobility flows, critical influence in the City functionality. The most affected services among urban sectors would be waste collection and cleaning services, but also the power sector may be subjected to major damages because the energy supply depends on fuel and therefore a failure in its transportation provokes alterations o failures in the energy sector as well.

The last urban element jeopardized by climate change hazards in Barcelona is represented by green infrastructures, which are vulnerable to: severe wind, heat wave, extreme hot weather drought, forest fire, flash/surface flood, river flood, coastal flood, storm surge and salt water intrusion.

In ***Bristol***, the main vulnerable sectors, analysed within RESCCUE project, are: power, urban water cycle, waste and transport. About the **power sector**, just power transmission and power distribution sectors are vulnerable, while power generation is not. In particular, elements as substations, overhead lines and underground cables are vulnerable to windstorm and snow. Therefore, the main direct consequences are damages, collapse and interruption of energy supply. Among cascading effects, water supply, urban drainage, waste water treatment, traffic control and telecommunication services may be subjected to disruption.

Water supply, urban drainage and waste water treatment are the vulnerable sectors of the urban **water cycle sector**. Critical elements are: distribution networks, pumping stations, water treatment plants and sewer networks, which are vulnerable to: heat wave, sea level rise, urban flooding, drought and CSOs. Main consequences of these events are: insufficient availability, limitation in supply, treatments performance reduction, limited conveyance capacity, high street water level and velocity, water quality deterioration, excessive inflow. Among the main cascading effects, there are: energy supply failure, mechanical failure, telecontrol failure, communication disruption and road traffic disturbance.

Regarding **waste sector**, the only vulnerable elements have been identified in the Solid Urban Waste Collection (SUW) subsystem. In particular, the vulnerable element is represented by waste vehicles. They are vulnerable to urban flooding, which can provoke damage and road closures. Also cascading effects can occur on urban drainage, like obstruction of components and surface flows.

The last vulnerable sector identified in Bristol is the **transport** one, in particular roadways and rail. Critical elements are: roads, traffic signals and railway tracks (both superficial and underground elements). They are vulnerable to: sea level rise, urban flooding, windstorm and snow. Main consequences are: interruption of public and private transportation, failures of traffic control systems and damage to underground infrastructures.

2 Multisectorial resilience strategies framework

Within the RESCCUE project the concept of resilience adopted is aligned with the one proposed by the United Nations International Strategy for Disaster Reduction (UNISDIR, 2009): The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. RESCCUE project understands the system as a city (Bristol, Barcelona and Lisbon) and its essential basic structures and functions are the different urban sectors and services as well as their interactions.

In order to achieve this "ability", consequences of different climate impacts must be understood first, and proper adaptation strategies have to be consequently proposed. The specific adaptation strategies can be formed by one or more general adaptation measures to cope with today and future's climate impacts on urban areas. In this regard, some brief descriptions must be conducted in this section in order to distinguish between measures and strategies unequivocally. Both descriptions have been adopted from BINGO EU project terms (Rocha *et al.*, 2017):

- **Adaptation measures**: are specific interventions to address a specific climate risk. This can be a measure that for example
    - Prevents a hazardous event from happening
    - Reduces or deflects the impact of a hazardous event
    - Improves recovery after a hazardous event has happened

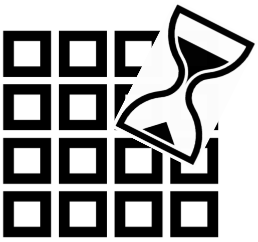
  Measures can be technical, infrastructural, but also legal, economical or social. So a measure could be building a dam, increasing the price of drinking water or raising awareness of flood risks.
- **Adaptation strategies**: are a collection of measures linked to specific risks and their impacts. The strategy provides a framework of which the measures are the practical outcome. A strategy consists of:
    - Identification of the risks and their impacts
    - Strategic goals that need to be achieved
    - Measures that help achieve those goals by addressing the risks
    - Implementation plan for the measures

  The analysis in this phase will be based on the individual measures, but the outcome will be beneficial in developing the strategies.

On the other hand, the difference between **mitigation and adaptation** should be noted also, seeing that although both are complementary and essential aspects of climate protection, these are not addressed in the same manner. Whilst the first, within the framework of climate change, is mainly focused on the reduction of greenhouse gas emissions, the second one, in case of cities, means the establishment of measures to decrease the vulnerability and increase the resilience facing those not desirable effects (Ventayol, 2014).

Addressing mitigation and adaptation jointly can maximize the benefits of actions taken and ensure that any action taken in pursuit of one goal does not undermine progress toward the other. On a global scale, successful early mitigation efforts may reduce future harms and related adaptation costs, but some climate change impacts are already unavoidable in some parts of the world and will require adaptation (ICLEI 2010). In RESCCUE project only adaptation strategies are considered.

The three key variables proposed here to make decisions for the adaptation strategies selection are: the strategies estimated cost, the co-benefits, and the recovery time reduction.



1. Recovery time reduction

2. Co-benefits

3. Strategies estimated cost

In order to consider the impact reduction in the cities that may provide a certain adaptation measure/strategy, a matrix which relates 32 urban services with 5 hazards (i.e. Flood, CSO, drought, heat wave, and sea level rise) has been proposed to be linked to each adaptation measure (Figure 2). It defines how effective the application of a measure is for certain services affected by hazards, but also how it is jeopardizing the recovery capacity of another. The global resilience level of the city could decrease if it occurs.

	Flood*	CSO*	Drought*	Heat Wave*	Sea Level Rise*
Service	Variation of recovery time [%]				*Click to see Justification
WATER					
Urban Drainage	-33	-33	0	0	0
Water Storage	-33	-33	-33	-33	0
Water treatment	-33	-33	0	0	0
Water Transportation	-33	-33	-33	-33	0
Wastewater Treatment	-33	-33	0	0	0
Treated wastewater reuse	0	-33	0	0	0
Power Generation	0	0	0	0	0
Power Distribution	0	0	0	0	0
Power Transportation	0	0	0	0	0
High Speed Roads	0	0	0	0	0
Streets	-33	-33	-33	0	-33
Subway	-33	-33	0	0	0
Train	0	0	0	0	0
Tram	0	0	0	0	0
Bus	-33	0	0	0	0
Port	0	0	0	0	0
Airport	0	0	0	0	0
Waste Collection	0	0	0	0	0
Waste Treatment	0	0	0	0	0
Landline Telephone	0	0	0	0	0
Mobile Telephone	0	0	0	0	0
Internet	0	0	0	0	0
Civil protection	0	0	0	0	0
Fire	10	0	10	33	0
Medical emergency	0	0	0	0	0
Local police	0	0	0	0	0
Public health	-33	-33	-33	10	0
Green infrastructures	-66	-33	-33	-33	-33
Beaches	0	0	0	0	0
Schools	-33	0	0	0	0
Gas distribution	0	0	0	0	0

Figure 2. Example of a variation of recovery time matrix related to a specific adaptation measure

The selected variable for this matrix has been the percentage of variation of the time a specific urban service is expected to be down. The "what if matrix" in the Hazur® platform (see Hazur® approach in Annex 3) establishes the period of time (down time) during which either a service or an infrastructure becomes inoperable or is not performing its proper function due to a certain impact (e.g. Flood, heat wave, drought or sea level rise). Therefore, the proposed matrix is expected to act on the "what if matrix", in order to modify the initial down times with new values which lead to obtain a **reduction on the city recovery time**. This matrix has been named as Variation of Recovery Time matrix (VRT).

The concept of recovery time is not a new one within the resilience framework, since it can be found in some works employed as a resilience indicator. Bruneau *et al.* (2003) for instance, introduced the concept of resilience triangle (Figure 3), which indicates a significant and a sudden decrease of functionality due to an extreme event at a certain time instant, followed by a gradual recovery of functionality, until it is fully functional after a time increment (recovery time).

- Often estimated through some combination of simplified modelling, past experience, and/or expert opinion.
- Recovery times for services supported by the built environment have a direct impact on the economic vitality and social well-being of the community.

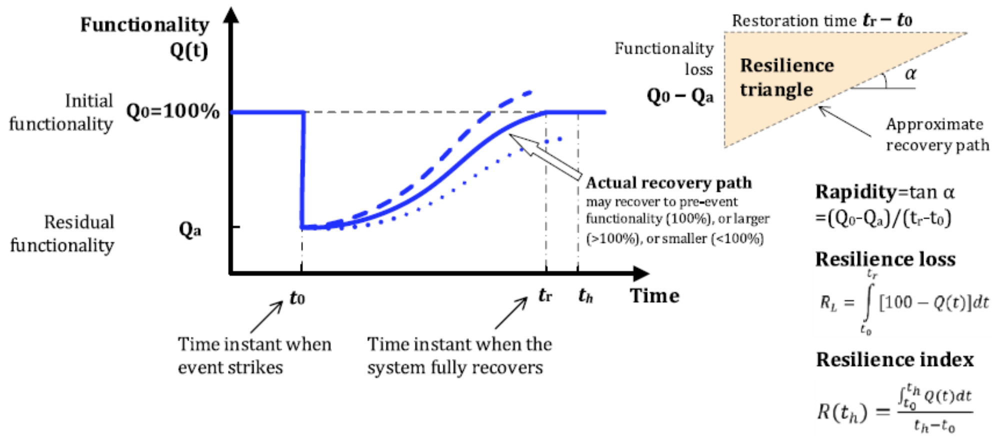


Figure 3. Resilience triangle and resilience index (source: Sun *et al.* (2018))

The engineering laboratory of the National Institute of Standards and Technology (NIST) (U.S. Department of Commerce) (Kwasinski *et al.*, 2017) states that the recovery times is one of the primary types of resilience metrics which present three main characteristics:

- Easy to grasp as goals, but difficult to predict with confidence.

Another example would be the San Francisco Planning and Urban Research Association (SPUR), that in order to establish metrics for earthquake-related resilience in San Francisco, developed its own methodology based on the recovery time as a resilience index. Therefore, the use of this variable within this framework is not a new approach, although here more variables are taken into account jointly (i.e. co-benefits and strategies estimated cost) to assess the adaptation strategies effectiveness.

Thus, when a certain adaptation measure/strategy is applied, the down time of the targeted services is expected to be reduced, and therefore the city recovery time. This effect will be applied through the variation of the recovery time matrix (VRT). In a certain manner, the weight of the effect of a measure for each service and due to each potential impact (i.e. hazards) is being offered with this matrix. Therefore, a variation of recovery time matrix (VRT) is a matrix which gathers percentages of variation of down times of all considered services (i.e. rows) according to different hazards (i.e. columns) (Figure 2).

Adaptation strategies (formed by individual adaptation measures) are the proposal to bridge the city gaps to increase resilience. Thus, the obtained co-benefits and the expected city recovery time reduction, result of applying a strategy, will be the aggregation of the effects of the measures which form the strategy. Therefore, each strategy will include its corresponding weighted co-benefits matrix and the variation of recovery time matrix (VRT) (Figure 4), which will be the result of a measures-related matrices operation (Figure 5 and Figure 6). The same procedure has to be conducted to obtain the matrices (i.e. co-benefits and VRT) related to a set of strategies.

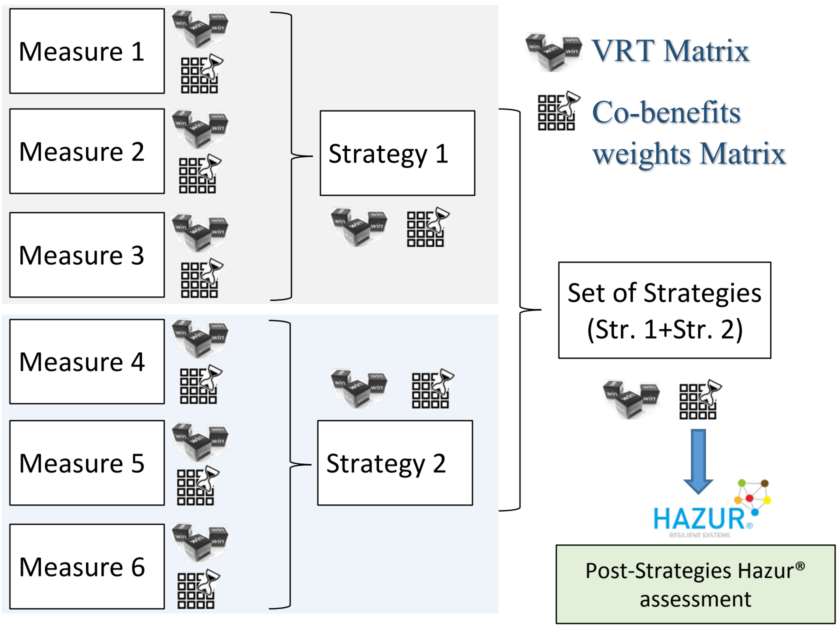


Figure 4. Outline of the aggregation of VRT matrices and co-benefits weights matrices, from measures to strategies, and from strategies to set of strategies

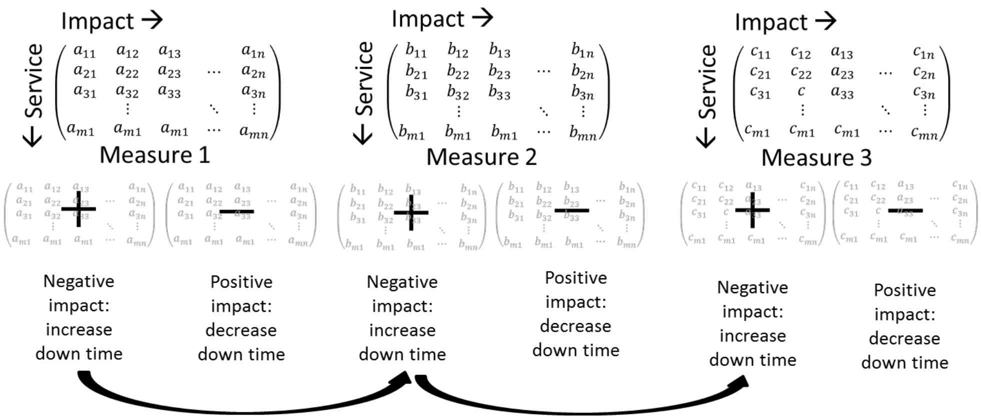
The complexity of the interrelation among urban services leads us to consider aspects such as cascading effects, which is comprehensively treated thanks to the use of the software-based solution Hazur®. The initial resilience state for each research site (i.e. Bristol, Barcelona, and Lisbon) will be established thanks to the resilience assessment in each city by means of Hazur®.

If effective adaptation strategies have been implemented the city resilience should increase. Therefore, a *post-strategies city resilience state* will also be assessed through Hazur® in order to evaluate how effective these strategies are. Hence, the ultimate objective of varying the "what if matrix" (down times) of Hazur® platform through the VRT matrix (from either one strategy or a set of them) is to be able to assess the effectiveness of the strategies in the city and the expected reduction on both the cascading effects (Figure 4) and the city recovery time.

Consequently, both a co-benefits weights matrix (Figure 8) and a VRT matrix (Figure 2) for each measure are needed to be defined. Although a proposal of matrices will be done here, these matrices will be able to be adapted to any other city if needed. In the case of the VRT matrix definition, a % of variation of the down times for each service and impact, either a decrease (-) (Figure 6) (i.e. the measure improves the down time to a service for a particular impact), or an increment (+) (Figure 6) (i.e. the measure jeopardizes the recovery capacity of a service for a particular impact).

The mathematical approach proposed to obtain the aggregated matrices for a strategy and, similarly, for a set of strategies is depicted following. It starts from the separation of positive and negative matrices which are processed separately as shown in Figure 5 and Figure 6 respectively.

Secondly, the resulting positive (D^+) and negative (D^-) matrices are joined back to form the VRT matrix for a strategy ($D = D^+ + D^-$). Once the VRT matrix is obtained for a strategy, the same process has to be conducted to obtain the VRT matrix for a set of matrices if needed. Either sole strategy or a set of them may be interesting to analyse the effectiveness by modifying the “what if” matrix (i.e. down times) in Hazur®. The co-benefits weights matrix has to be processed in the same way.

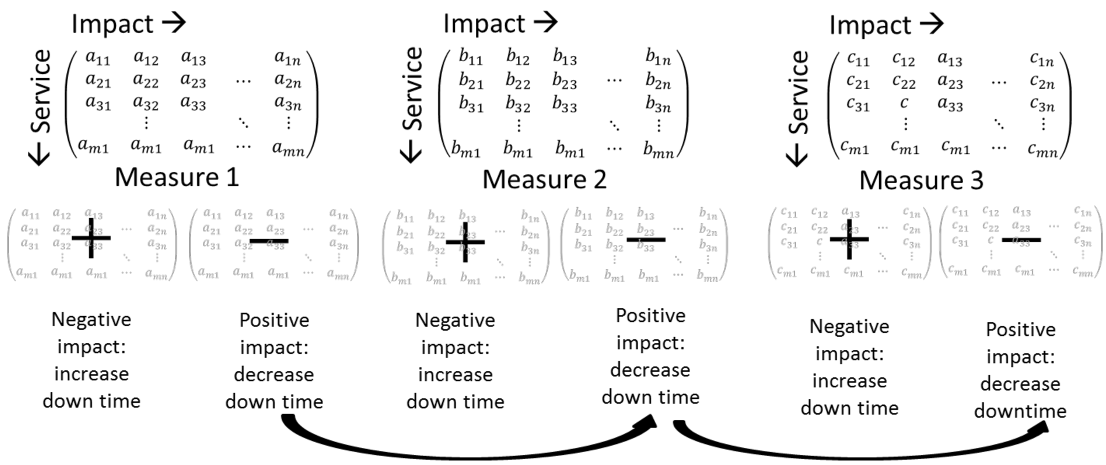


1. Vector of coordinates sorted from higher to lower values $\vec{x} = (b_{11}, c_{11}, a_{11})$
2. A new strategy matrix will be obtained (D+), where

$$d_{11} = |b_{11}| + \left[|b_{11}| \cdot \frac{|c_{11}|}{100}\right] + \left[\left(|b_{11}| + \left[|b_{11}| \cdot \frac{|c_{11}|}{100}\right]\right) \cdot \frac{|a_{11}|}{100}\right]$$

$$D^+ = \begin{pmatrix} +d_{11} & 0 & +d_{13} & & 0 \\ +d_{21} & +d_{22} & +d_{23} & \cdots & +d_{2n} \\ 0 & 0 & +d_{33} & & 0 \\ & \vdots & & \ddots & \vdots \\ 0 & +d_{m1} & 0 & \cdots & +d_{mn} \end{pmatrix}$$

Figure 5. Mathematical approach of the aggregation of VRT matrices of negative impact



1. Vector of coordinates sorted from higher to lower absolute values $\vec{y} = (|a_{12}|, |c_{12}|, |b_{12}|)$
2. A new strategy matrix will be obtained (D-), where

$$d_{12} = |a_{12}| + \left[\left[(100 - |a_{12}|) \cdot \frac{|c_{12}|}{100}\right] + \left[\left[(100 - |a_{12}|) \cdot \frac{|c_{12}|}{100}\right] \cdot \frac{|b_{12}|}{100}\right]\right]$$

$$D^{-} = \begin{pmatrix} 0 & -d_{12} & 0 & & -d_{1n} \\ 0 & 0 & 0 & \cdots & 0 \\ -d_{31} & -d_{32} & 0 & & -d_{3n} \\ & \vdots & & \ddots & \vdots \\ -d_{m1} & 0 & -d_{m1} & \cdots & 0 \end{pmatrix}$$

Figure 6. Mathematical approach of the aggregation of VRT matrices of positive impact

Figure 7 shows an example of the application of the previous mathematical approach, in order to obtain the VRT matrix for a strategy on the basis of two measures which form it. Moreover, it is depicted how this matrix modifies the "what if matrix" (Figure 25) of Hazur®, thereby permitting to assess the strategy effectiveness through Hazur®.

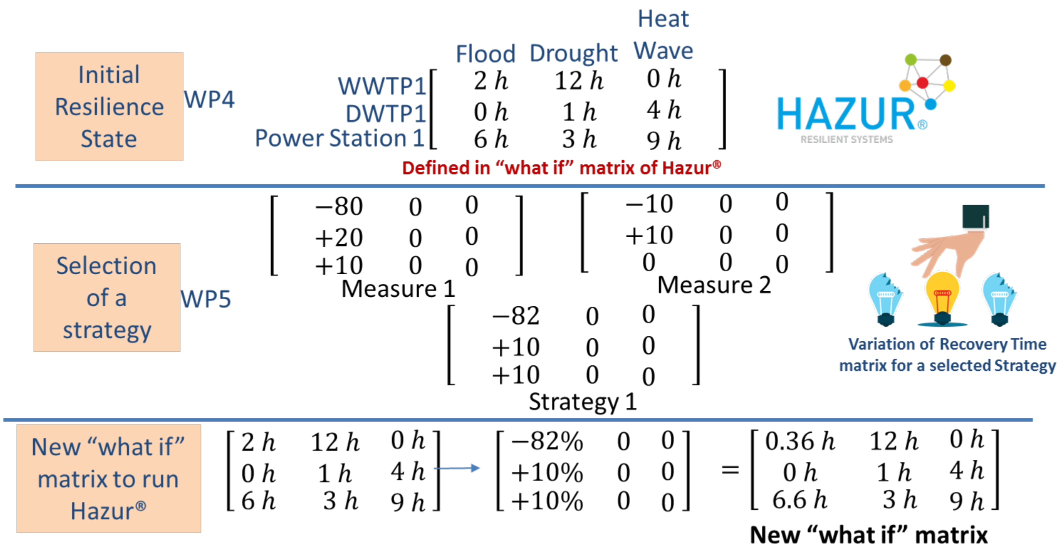


Figure 7. Example of a matrices operation

On the other hand, another essential information to be provided to each adaptation measure is the possible **co-benefits** that may occur when implementing a specific measure. A co-benefit resulting from an adaptation measure/strategy means that it is an additional benefit, different from the one the measure/strategy is targeted on, and which is not necessarily 'climate related'. The evidence suggests that citizens are more likely to take action on climate change, or more likely to support governments that take action on climate change, if the wider co-benefits of those actions are emphasised (Bain *et al.* 2015). At the city level, the potential of co-benefits is particularly great as citizens can often witness the results of policy actions more directly on their daily lives (Floater *et al.*, 2016). Several names for the same definition can be found in literature, such as win-win situations, life-cycle benefits, triple-win scenarios, consequential benefits, ancillary benefits, mutual benefits, consequential life cycle impacts, etc.

Ürge-Vorsatz *et al*. (2014) states that co-benefits should be included in decision-support frameworks. In this sense, a list of co-benefits, grouped in three different types (i.e. economic, social and environmental), has been proposed herein (Table 3). These co-benefits are based on those proposed in the report "Co-benefits of urban climate action: A framework for cities", developed by C40 Cities climate leadership group and LSECities (Floater *et al.*, 2016). Therefore, within the required information for each measure, the importance of each listed co-benefit will be considered by establishing a weight from zero (no effect) to ten (totally beneficial) (Figure 8). Somehow, it has to be considered as a matrix of weights of co-benefits related to each adaptation measure.

Table 3. Types of co-benefits proposed to be associated to the different adaptation measures

Economic	Social	Environmental
• Cost savings	• Reduced mortality impacts	• Improved air quality
• Reduced energy losses	• Reduced health impacts	• Improved water quantity
• Job creation	• Reduced mortality from diseases	• Reduced aquifer depletion
• Possible reduction in prices	• Enhanced public amenity	• Reduced water pollution
• Increased labour productivity	• Reduced impacts on vulnerable groups	• Reduced land contamination
• Increased economic production	• Reduced number of householders, businesses forced from homes, places of work	• Improved biodiversity and ecosystems
• Increased property values	• Social inclusion	• Maintained and increased green space
		• Reduced environmental impacts through associated awareness
		• Increased biodiversity and ecosystem services
		• Effective/uninterrupted water collection and security
		• Erosion control

Economic	Weight [0-10]	Social	Weight [0-10]	Environmental	Weight [0-10]
Cost savings	0	Reduced mortality impacts	6	Improved air quality	8
Reduced energy losses	6	Reduced health impacts	7	Improved water quantity	7
Job creation	2	Reduced mortality from diseases	1	Reduced aquifer depletion	6
Possible reduction in prices	2	Enhanced public amenity	9	Reduced water pollution	9
Increased labour productivity	0	Reduced impacts on vulnerable groups	1	Reduced land contamination	5
Increased economic production	6	Reduced number of householders, businesses forced from homes, places of work	0	Improved biodiversity and ecosystems	10
Increased property values	0	Social inclusion	1	Maintained and increased green space	10
				Reduced environmental impacts through associated awareness	6
				Increased biodiversity and ecosystem services	10
				Effective/uninterrupted water collection and security	7
				Erosion control	2

Figure 8. Example of co-benefits for a certain measure and its corresponding weights

Finally, another important reason for a decision maker for implement a specific adaptation strategy is its cost, not only the initial investment but also the cost burden resulting from its maintenance. Therefore, their **estimated cost** will be related to each proposed adaptation strategy as an important variable in order to make decisions to select them, and also in a second stage when a cost benefit analysis (CBA) will allow to prioritize the selected strategies.

According to the characterization of measures observed during the literature review, and also based on real necessities of the city councils involved in this project, the requested information to describe a measure (in addition to the co-benefits and VRT already presented), is shown in Figure 9. Not only the measure description is proposed to be included, but also aspects such as if there exist an official application to implement it, the source where this specific measure can be found described or the institution that proposed the measure.

Regarding adaptation strategies, also specific information is proposed to characterize them (Figure 10). As strategies are tailored for a city or a specific case, an essential information is the city where it is expected to be implemented. The measures needed to fully implement the strategy have to be listed too. In addition, problem description, objectives and the institution/s which will deal with its implementation are also data to be collected for a strategy. Finally, economic details (i.e. estimated costs and sources of funding) have to be referred to each strategy. As stated at the beginning of this section, the **strategies estimated costs** will be one of the three key variables proposed here to make decisions for the adaptation strategies.

RESCCUE
RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

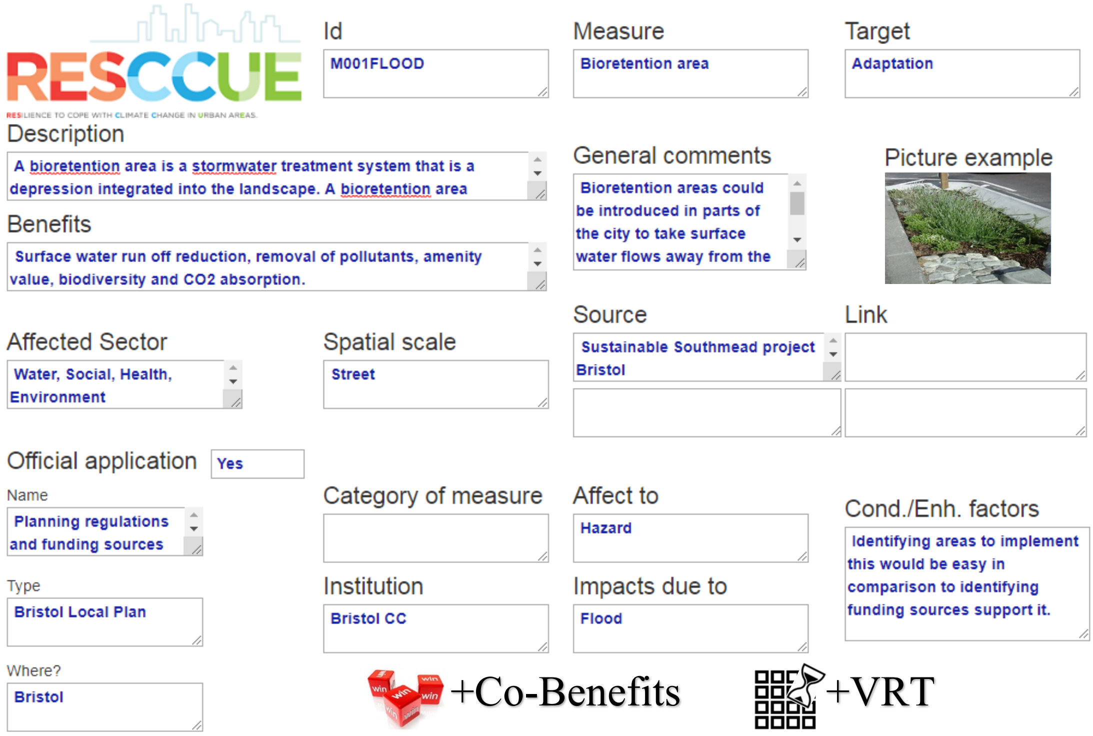


Figure 9. Fields to characterize a measure

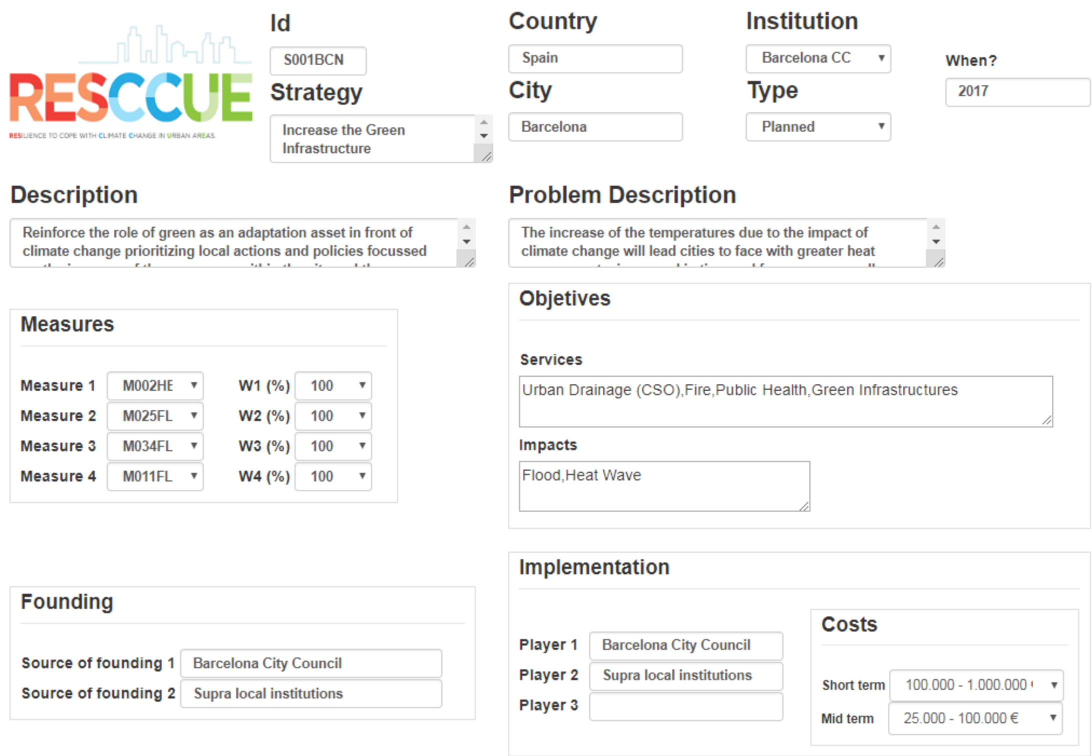


Figure 10. Fields to characterize a strategy

Based on a shared partners' knowledge, and taking advantage of the city councils as partners of the project, 94 adaptation measures have been gathered by forming a **database**. Different kinds of adaptation measures have been incorporated in this database, both technological and non-technological, as well as ecosystem based approaches and communication system enabling stakeholder participation.

In this manner, after assessing how resilient the three cities are (Bristol, Barcelona and Lisbon), different adaptation strategies will be created first and selected later to be implemented, based on the adaptation measures database. This database has been included in a **decision support application** (web-based platform) in order to facilitate the strategies creation, which calculates (Figure 5 and Figure 6) also the corresponding couple of matrices (i.e. co-benefits and VRT) for the strategies created. Therefore, after the strategies selection the "what if" matrix may be modified by employing the obtained VRT matrix, and a different outcome will be obtained by Hazur® (post strategies resilience status) (Figure 7).

As a result, the strategies effectiveness will be proven not only by means of a new Hazur® assessment (holistic approach), but also taking into account the aggregated effect of the co-benefits of the selected adaptation strategies, and through a risks re-assessment by implementing them on the sectorial models (detailed approach). This proposed framework is outlined in Figure 11.

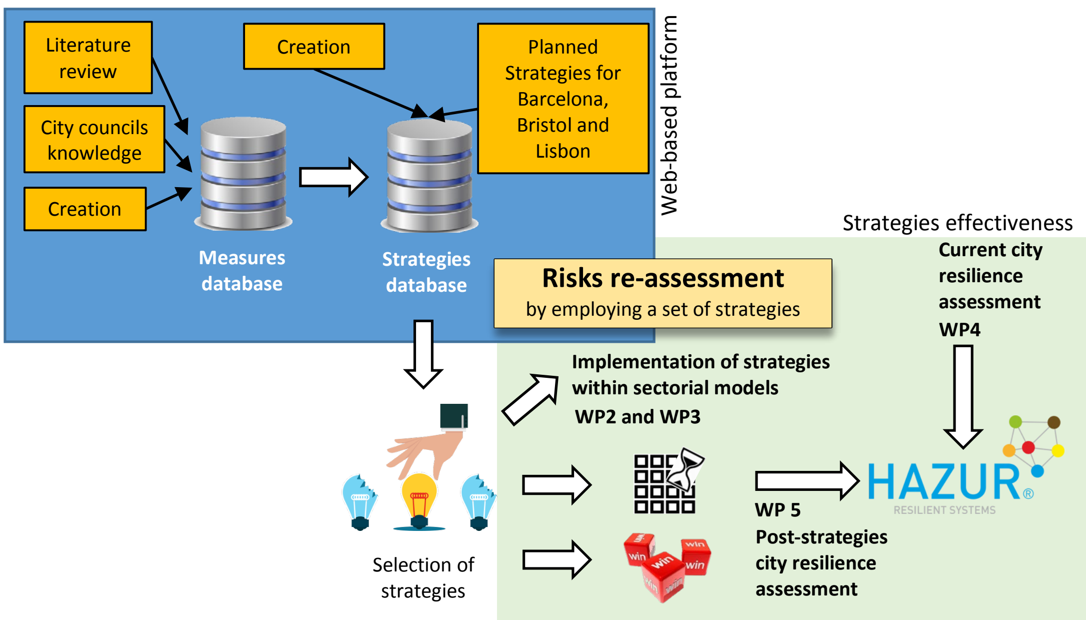


Figure 11. Outline of the multisectorial resilience strategies framework

3 Web-based platform

The web-based platform will offer firstly a set of adaptation measures (e.g. street cleaning, increase in the number of drainage inlets, etc.) to create adaptation strategies for Bristol, Barcelona and Liston (and other cities after the RESCCUE project). A first set of strategies, based on the resilience plans that the cities already have developed, have been created, but new ones can be created and modified if necessary by the user (i.e. stakeholders and decision-makers) according to their specific needs.

In order to create the measures database, it was necessary to receive contributions from all the partners involved in this task who have knowledge on specific sectors, and hence on adaptation measures related to these sectors. In order to carry out this task a google form was developed, taking into account all previously described fields to characterize the adaptation measures. This form was sent out to all partners in order to collect all adaptation measures in a proper manner. Subsequently, all this information was gathered to form the database. Adaptation strategies were straightaway defined within the new web-based platform.

Once the diagnosis of current situation within a city is done, which will lead to an initial pre-selection of strategies, decision makers can use this web-based platform. The use of this decision support application aim at supporting the strategies effectiveness study to make the **selection of strategies**.

In the following sections, both the system architecture criteria of the database and the web-based platform interface are comprehensively described.

3.1 System architecture criteria of the database

The architecture specification process described in the following section has been guided by a combination of technical and organizational aspects. Together with the collected requirements on functions to be supported and targeted integrations, additional considerations on licensing models, scalability or governance have also been processed to provide an optimal technological stack from a multi-criteria point of view.

- **Data requirements**. Modern data storage solutions bundled within the NoSQL concept have shifted towards a data-centric approach. Instead of having a single solution for all kinds of data, today's databases are tailored for the kind of data they're expected to store.

  In this case, adaptation measures and strategies can be represented as documents. Additionally, since some variability is expected in the structure of the different measures and strategies, a schema-less storage solution is required.

  By combining both constraints, a document-based database providing a schema-less storage has been identified: MongoDB. MongoDB is the market leader for document-oriented databases, providing service to major use cases across all kind of industries and supported by a robust user community.

- **Usage requirements**. According to the functional specification previously described, the system database must support the following functions
  - Bulk load of data: data initially ingested through *Google Forms* will be jointly loaded through a one-time script.
  - CRUD access on data. Create, Read, Update and Delete operations on existing adaptation measures and strategies is to be supported.

  MongoDB supports both functions though a well-designed REST API. Bulk data loads and all the required verbs are exposed and documented through the API. Together with the API, native clients for the major operating systems and drivers for every relevant programming language are equally available.

- **Scalability requirements**. Although no tight requirements on scalability or performance are envisioned within the project scope, system architecture is conceived as scalable by design. This decision enables a city-wide and nation-wide exploitation potential (much beyond the current scope). MongoDB is a highly-scalable database based on a distributed architecture on commodity clusters. Big Data requirements on volume, velocity and variability could therefore be met by the provided system.
- **Governance requirements**. MongoDb and all the technologies included in the described system architecture (Express, Angular and Node.js supporting the user application) are based on free and open source licenses (AGPL for MongoDB, MIT for Express, Angular and Nodejs). No usage fee or constraint is defined, and all software fonts are available and maintained by the community.

Table 4. System components involved in the database elaboration process and roles

System component	Role
Google Form and Sheet for initial data collection	Web-form based on Google technologies used for preliminary ingestion of data by project stakeholders
One-time data loading script	Google Sheet script providing a one-time load of initial data into the main system database
Measures and strategies database	Main data storage in the system. MongoDB database with two separate collections for strategies and measures
Data Access API	REST API on the main system database enabling CRUD operations on measures and strategies.
Measures and strategies web app	User application enabling web-based access on the measures and strategies data

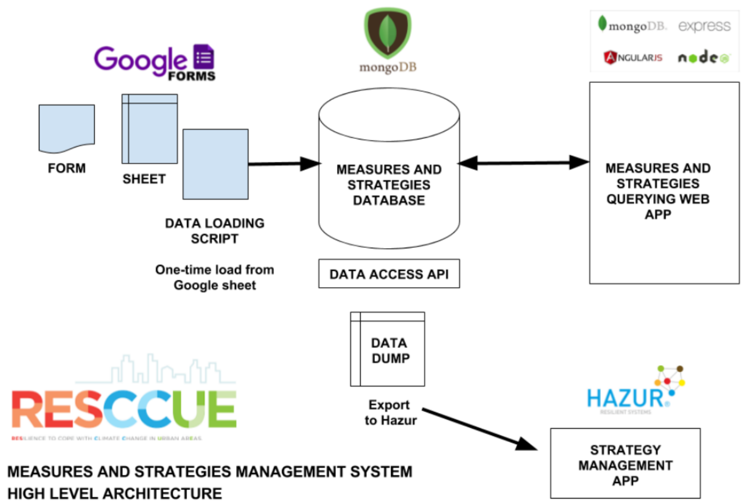


Figure 12. Outline of the process from data collection to exportation

The database will contain two collections hosting the two different documents handled by the system:

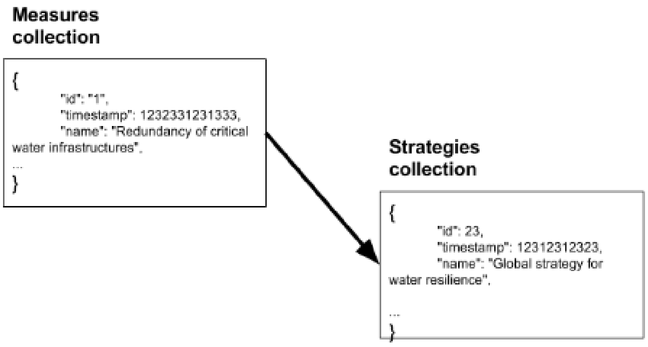


Figure 13. Two Collections: measures and strategies

Since regular content updates are expected and no massive scalability requirements are envisioned, no de-normalization of data has been defined. Therefore, measures and strategies are individually stored, and strategies keep a reference on the included measures enabling the joint querying of a strategy and the measures it contains.

The database will support three different uses within the system architecture:

- One-time data load from Google Sheet. Data collected in Google Form will be pushed from its backend Google Sheet to MongoDB. In order to do so, a script will be created to submit POST operations to the database API:

```
function pushToDB(row){
var db_name = "";
var coll_name = "";
var api_key = "XXXX Enter your API key here XXXX";

// Forming RESCCUE URL
var base_url = "https://api.rescuue.com/api/1/databases/";
base_url += db_name + '/collections/';
base_url += coll_name;
base_url += '?apiKey=' + api_key;

//post
var options =
{"method":"post","payload":JSON.stringify(row),"contentType":"application/j
son"};
return UrlFetchApp.fetch(base_url, options);
}
```

- CRUD access supporting the user application. The MongoDB REST API support all the operations required to build a user interface to query the contained data. The stack used to build the user application (MEAN, standing for Mongo, Express, Angular and Node) is fully consistent with this REST-based approach, being the current de-facto stack for modern web applications.

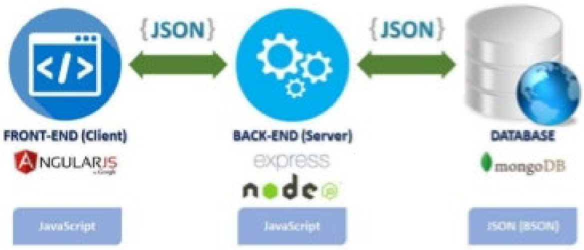


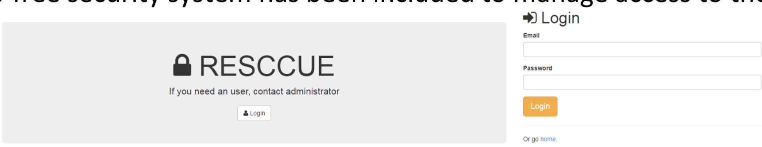
Figure 14. Database-Server-Client

- Data exports. MongoDB API natively supports data dumps to CSV and JSON files, so integration with all kind of legacy systems is available.

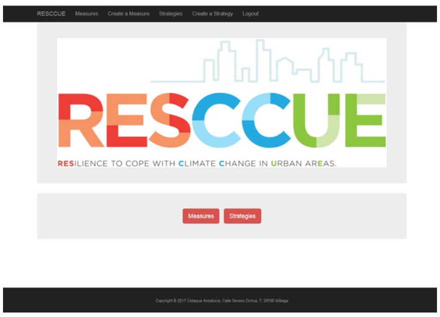
3.2 Web-based platform interface description and use

A web application (https://resccue.herokuapp.com/) that allows to manage the database stored in MongoDB on the BBDD hosting server MLab has been developed. It uses the Heroku platform, specially designed for MEAN Stack application hosting.

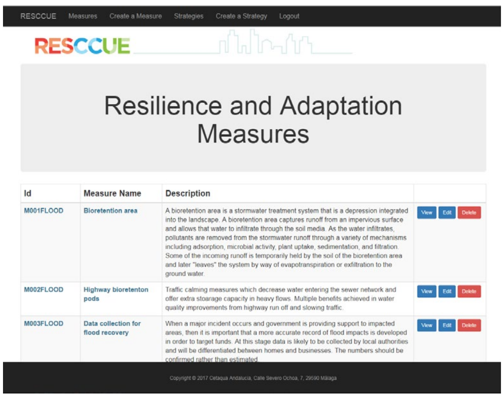
A basic, role-free security system has been included to manage access to the application.



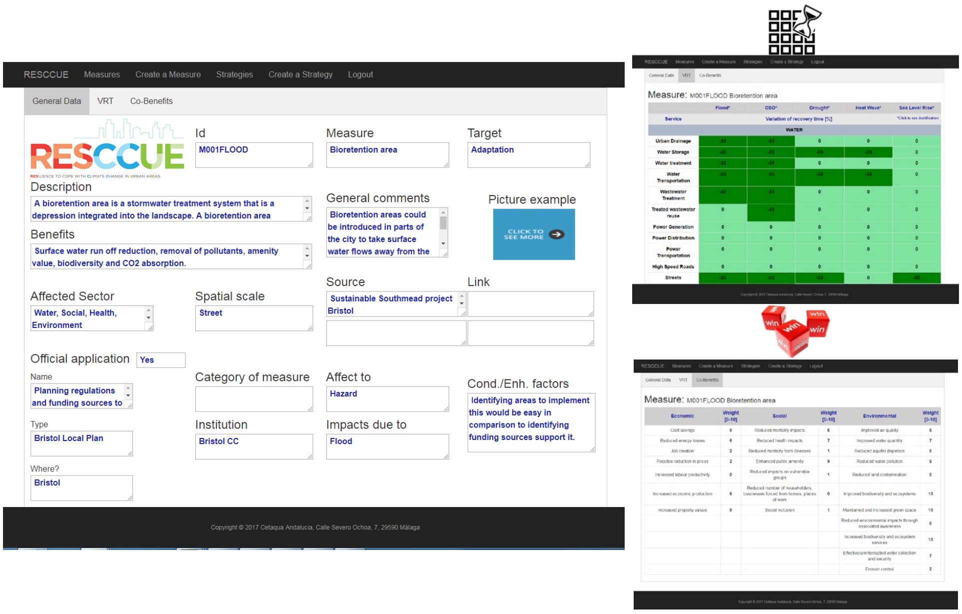
The initial screen allows to choose between Measures or Strategies.



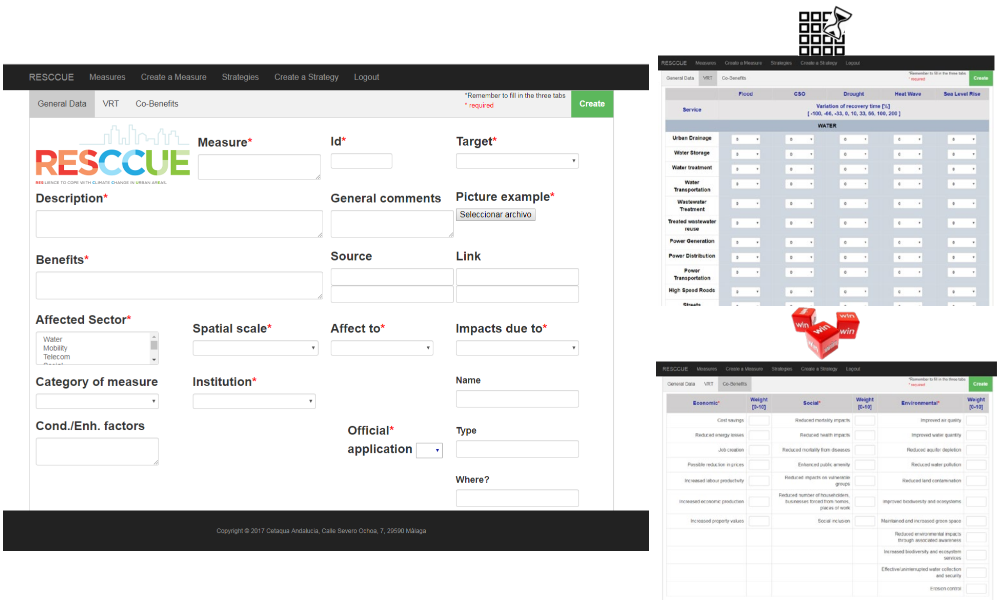
1. Display all recorded measures:



2. Display a particular measure:

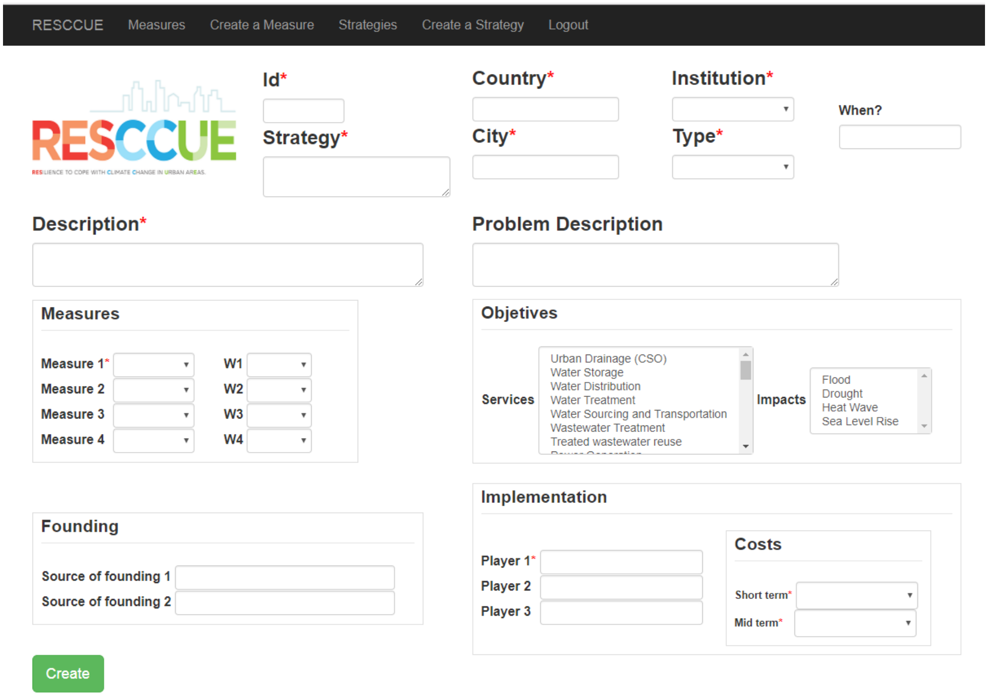


3. Introduce a new measure:



The same structure has been considered when it comes to strategies, whether general visualization, individual or creation of new strategies.

In the creation of a new strategy, the user will be able to choose the measures that form it, from which were previously generated. It is shown in the picture below.



In this way, the database can be managed, both in the visualization of the measures and strategies already saved, as well as in the creation of new measures and strategies.

3.3 Overview of the considered adaptation measures

As mentioned in previous sections, 94 measures have been gathered within a database thanks to the contribution of the partners involved in this task. To do this, a google form was done and shared with them to be filled in, taking into account all fields that have been established within the proposed framework in order to characterize the adaptation measures properly. Before outlining the main characteristics of the stored adaptation measures, a complete list of the 94 measures is shown below in Table 5. The summary of reviewed projects related to climate adaptation measures for specific sectors can be found in the Annex 3)

Table 5. List of 94 measures that forms the database currently

Id	Measure name
M001FLOOD	Bioretention area
M002FLOOD	Highway bioretenton pods
M003FLOOD	Data collection for flood recovery
M004FLOOD	Demountable flood protection barrier
M005FLOOD	Learn from real-life flooding by recording and investigating events
M006FLOOD	Gather, manage and share high quality data to help understand the risk of flooding
M007FLOOD	Create and maintain Flood Risk Asset Registers to identify key flood risk assets and who is responsible for their maintenance
M008FLOOD	Identify high risk areas by conducting studies involving flood modelling analysis
M009FLOOD	Develop community flood plans
M001SLRISE	Build riverside flood defence walls
M010FLOOD	Install flood proof fencing
M011FLOOD	Adding rain gardens before sewer inlet points
M012FLOOD	Introduce rock armour in rivers to add erosion protection against flood defence assets
M001DROUGHT	Use of non-potable water in compatible
M013FLOOD	Emergency response plans and procedures
M014FLOOD	Implementation of Rainwater Harvesting systems (RWH)
M015FLOOD	Retention tanks and storage sewers
M016FLOOD	Rehabilitate sewer pipes
M017FLOOD	Inlets increase
M018FLOOD	Implement grates at upstream entrances on the sewer network
M019FLOOD	On-source sediment traps
M001CSO	Filter drain
M020FLOOD	Filter strip
M021FLOOD	Increase commitment to develop risk management strategies
M022FLOOD	Define and improve pre-disaster plans
M002DROUGHT	Increase of water storage capacity
M003DROUGHT	Prioritize water allocation in a stress situation
M004DROUGHT	Use of water desalination (seawater, groundwater, brakish water)
M023FLOOD	Construction of diversion tunnels
M002CSO	Modification of existing CSO structures to locally delay the start of the overflow
M024FLOOD	Inspection and cleaning of drains or sewer pipes
M025FLOOD	Green roof
M026FLOOD	Maintenance of hydraulic structures of the storm drainage system
M003CSO	Eradication of wrong connections and discharges in drainage network
M027FLOOD	Construction of anti-pollution basins
M028FLOOD	Rehabilitation of the discharge conditions
M029FLOOD	Comprehensive approaches to rebuild urban areas
M030FLOOD	Identify high risk areas by conducting studies involving modelling analysis
M031FLOOD	Provide flood storage areas via detention, retention or infiltration basins
M032FLOOD	Increase the capacity of sewer drainage system

Id	Measure name
M033FLOOD	Filter trenches
M034FLOOD	Green wall
M035FLOOD	Permeable paving
M036FLOOD	Detention basin
M037FLOOD	Soakaway
M038FLOOD	Swale
M039FLOOD	Ponds and wetlands
M004CSO	End-of-pipe CSO treatment
M005DROUGHT	Adaption of intake infrastructure to handle low flows
M006DROUGHT	Use of alternative water source with adequate quality for supply
M001HEATWAVE	Minimization of residence times of water in the distribution network
M040FLOOD	Effective communication of risk, considering power relations among actors
M041FLOOD	Training, exercises and education to transfer scientific and operational knowledge to practitioners
M042FLOOD	Check valve and non-return valve
M043FLOOD	Disconnecting paved surfaces from sewer system
M044FLOOD	Increase height difference between street level and ground floor level
M045FLOOD	Increase the network of waterways
M046FLOOD	Public awareness, information, education and communication
M047FLOOD	Raise kerb or curb
M048FLOOD	Build a water square
M009MULTIPLE	Increase integration of renewable energy by Distributed Generation (DG)
M010MULTIPLE	Reinforce Electric Municipal fleet
M049FLOOD	Flood forecasting and warning
M050FLOOD	Street cleaning
M011MULTIPLE	Improving protection schemes to integrate renewable DG
M012MULTIPLE	Isolated operation of renewable energy microgrids
M051FLOOD	High water flood mark
M052FLOOD	Development of a mobile app to notify alerts to the general population and to allow citizens to report emergencies
M053FLOOD	Construction of anti-flood retention basins
M055FLOOD	Set emergency supplies and utilities storages
M056FLOOD	Implement storm weir devices
M005CSO	Rebuilding of combined sewer systems to separate sewers
M054FLOOD	Elevate buildings
M057FLOOD	Periodic inspection and maintenance of pumping systems
M058FLOOD	Increase pumping capacity
M059FLOOD	Use of buildings as flood defence
M060FLOOD	Develop a rescue plan
M062FLOOD	Artificial island
M063FLOOD	Flood proof crucial infrastructures
M001MULTIPLE	Improved preparedness
M002MULTIPLE	Improve interoperability of the crisis management actors by development or implementation of practical standards
M064FLOOD	Enlargement of treatment capacity in WWTP (wet weather lines) along with the collection capacity (including pumping stations)
M002SLRISE	Level up or relocate substations near coastal and river areas
M013MULTIPLE	Meshed operation of the distribution grid
M003MULTIPLE	Increase digitalization, communication and automation
M014MULTIPLE	Impact-based multi-hazard early warning systems
M004MULTIPLE	Elaboration of municipal archives on major hazards
M066FLOOD	Restriction on land-use areas vulnerable to flooding events
M002HEATWAVE	Build promote urban forest and park
M005MULTIPLE	Reinforce public transports

Id	Measure name
M006MULTIPLE	Set an emergency operation centre and personnel
M007MULTIPLE	Use of Social Media for warnings and information
M008MULTIPLE	Opportunities for citizens to participate in preparedness and response
M065FLOOD	Set update a flood hazard mapping

Both the co-benefits and the percentage of variation of recovery time, as mention previously, are key variables in order to make decisions related to the strategies selection. Since the strategies will be formed by measures, these two variables (i.e. a couple of matrices) have to be related first to each measure itself, and the ones corresponding to the strategy will be stablished through the aggregation-effects method proposed within the current fraework. However, the third key variable, estimated cost, will be considered once the strategy is created. Measures have to be standard to be employed for different cities (i.e. standard or universal), unlike strategies which will act in a specific city for a specific problem. Moreover, neither units nor specific details have been considered to characterize a measure, because this information is expected to be considered once the strategy is being created to solve a concrete problem. For these reasons no estimated costs are related to measures.

Regarding the co-benefits related to measures, as described in the framework, three groups have been considered: economic, social, and environmental. The percentages of measures (out of 94) with a specific weight (i.e. from 1 to 10) for the different co-benefits are shown in Figure 15, Figure 16, and Figure 17. Therefore, these figures indicate the importance of the different co-benefits among the gathered measures. It can be observed that the cost savings have been weighted with 5 out of 10 for more than 18% of the cases and with 7 out of 10 for almost 14% of them. An aspect to highlight is that 8% of the measures have been weighted with 10 out of 10 for social inclusion (social co-benefits) and 5% have also been weighted with 10 out of 10 for improved biodiversity and ecosistems, maintained and increased green space, and increased biodiversity and ecosystem services.

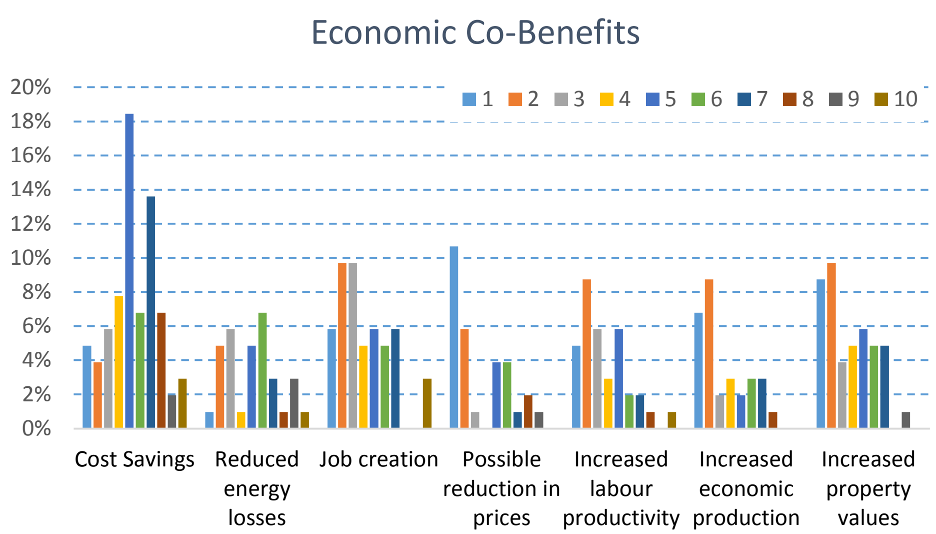


Figure 15. Percentages of the total number of measures according to the fixed economic co-benefits weights

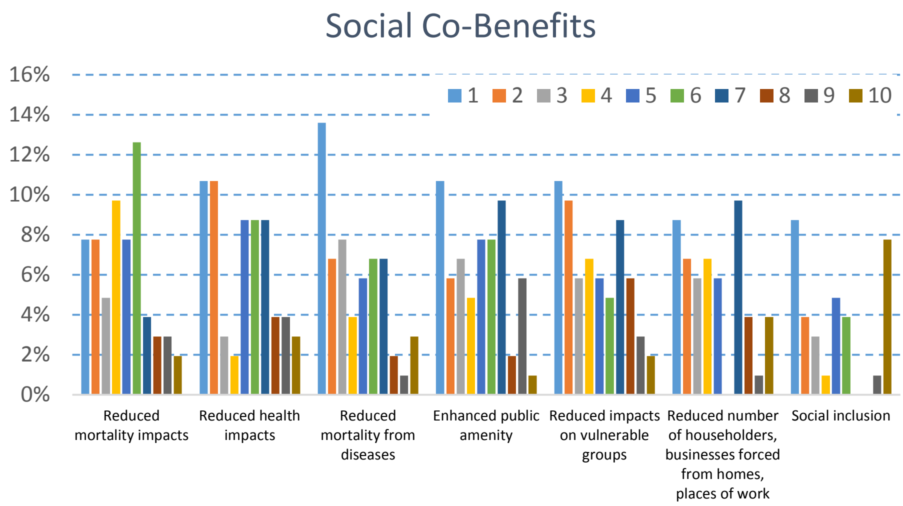


Figure 16. Percentages of the total number of measures according to the fixed social co-benefits weights

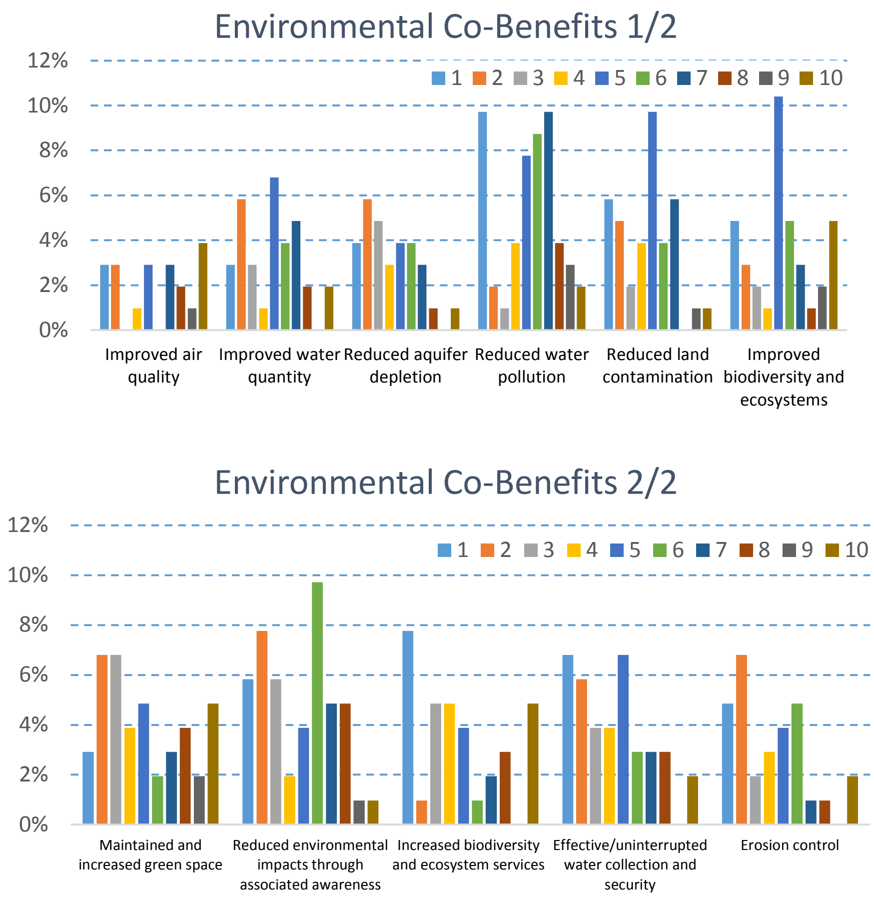


Figure 17. Percentages of the total number of measures according to the fixed environmental co-benefits weights

In Table 6 it is presented the number of measures according to the variation of the down times proposed for them, the potential hazard and the service affected. Nine fixed levels (i.e. -100, -66, -33, 0, 10, 33, 66, 100, 200) of variation of the down times were proposed to select one of them for each hazard and service related to an specific measure. The three negative fixed levels (i.e. -33, -66, and -100) indicate the percentage of reduction for the down times. In other words, it pretends to point out how the measure will increase the resilience (i.e. the city recovery time reduction) by reducing the down times for a certain service due to a potential hazard. A zero value indicates that there will not be changes in the down time, and positive values point out how the implementation of this measure may jeopardize the recovery capacity of a certain service (i.e. by increasing its down time).

Within Table 6 it can be observed that all measures will reduce their down time as a maximum of two thirds (i.e. -66), and mostly a 10% of increase is expected in some cases as a maximum. Only two measures were categorized with a third (i.e. 33) of increase of the down time. It should be noted that these values are the result of the proposal of different partners involved in this task, but these may be modified along the project lifetime, and by future web-platform users if they consider so. It has to be highlighted the value of the methodology proposed herein further than the figures.

Moreover, the measures gathered have been characterized with other information, further than only co-benefits and VRTs, which has been outlined in Figure 18, Figure 19, and Figure 20. Almost 60% of the measures have been classified as structural and 40% as non-structural (23% Social and 18% Institutional).

Also, Figure 19 denotes a certain unbalance regarding the affected sector, with 86% of measures aiming at the water sector. This is due to some reasons: 1) the higher expertise in this sector within the partners involved in the task, 2) the central role of water sector in the RESCCUE project, and 3) the importance of water services with respect climate risks. However, this unbalance is expected to be corrected along the lifetime of the project, because this database will be extended as the strategies creation requires it. This issue can be observed also when focusing on the field “impacts due to”, and for more than 70% of measures it was indicated as “Flood” (Figure 20).

To finalize the outline of the measures gathered, a graph where the “affect to” field information has been performed (Figure 20). Three options were available for this field: multisectorial nexus (e.g. redundancies, management improvements, responders...), hazard and vulnerabilities. A quite balanced distribution among all 94 measures can be observed.

Table 6. Number of measures according to the variation of the down times proposed, hazard and service affected

	Flood									Drought									Heat wave									Sea Level Rise									Combined Sewer Overflow (CSO)								
	-100	-66	-33	0	10	33	66	100	200	-100	-66	-33	0	10	33	66	100	200	-100	-66	-33	0	10	33	66	100	200	-100	-66	-33	0	10	33	66	100	200	-100	-66	-33	0	10	33	66	100	200
Urban drainage (CSO)	0	9	47	37	1	0	0	0	0	0	1	3	72	0	0	0	0	0	0	1	4	66	0	0	0	0	0	0	5	17	48	1	0	0	0	0	0	8	37	40	1	0	0	0	0
Water Storage	0	3	15	68	0	0	0	0	0	0	4	14	57	1	0	0	0	0	0	0	8	62	0	0	0	0	0	0	4	9	55	1	0	0	0	0	0	1	11	58	0	0	0	0	0
Water treatment	0	6	21	59	0	0	0	0	0	0	1	8	66	1	0	0	0	0	0	1	3	67	0	0	0	0	0	0	5	12	51	1	0	0	0	0	0	2	12	55	0	0	0	0	0
Water transportation	0	4	16	64	0	0	0	0	0	0	2	8	66	0	0	0	0	0	0	2	7	62	0	0	0	0	0	0	4	12	52	1	0	0	0	0	0	2	8	60	0	0	0	0	0
Wastewater treatment	0	5	35	52	2	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	2	68	0	0	0	0	0	0	4	13	51	1	0	0	0	0	0	1	23	56	0	0	0	0	0
Treated wastewater reuse	0	3	17	64	1	0	0	0	0	0	1	5	68	1	0	0	0	0	0	1	3	67	0	0	0	0	0	0	4	13	51	1	0	0	0	0	0	1	13	56	0	1	0	0	0
Power generation	0	3	10	72	0	0	0	0	0	0	2	7	65	1	0	0	0	0	0	2	8	61	0	0	0	0	0	0	4	10	54	1	0	0	0	0	0	1	5	64	0	0	0	0	0
Power distribution	0	5	24	57	0	0	0	0	0	0	2	6	67	0	0	0	0	0	0	2	10	59	0	0	0	0	0	0	5	14	49	1	0	0	0	0	0	2	6	62	0	0	0	0	0
Power transportation	0	5	19	62	0	0	0	0	0	0	2	6	68	0	0	0	0	0	0	2	9	60	0	0	0	0	0	0	5	11	52	1	0	0	0	0	0	2	6	62	0	0	0	0	0
High Speed roads	0	4	21	66	0	0	0	0	0	0	1	1	73	0	0	0	0	0	0	1	4	66	0	0	0	0	0	0	4	10	54	1	0	0	0	0	0	1	7	62	0	0	0	0	0
Streets	0	7	47	39	1	0	0	0	0	0	1	6	68	0	0	0	0	0	0	1	6	64	0	0	0	0	0	0	4	18	46	1	0	0	0	0	0	1	14	55	0	0	0	0	0
Subway	0	5	35	51	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	13	51	1	0	0	0	0	0	1	10	59	0	0	0	0	0
Train	0	5	27	61	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	14	50	1	0	0	0	0	0	1	7	62	0	0	0	0	0
Tram	0	6	29	58	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	6	64	0	0	0	0	0	0	3	9	56	1	0	0	0	0	0	1	3	66	0	0	0	0	0
Bus	0	7	41	45	1	0	0	0	0	0	1	3	70	0	0	0	0	0	0	1	5	65	0	0	0	0	0	0	4	15	49	1	0	0	0	0	0	1	9	60	0	0	0	0	0
Port	0	3	15	67	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	3	67	0	0	0	0	0	0	5	10	54	0	0	0	0	0	0	1	3	66	0	0	0	0	0
Airport	0	3	14	69	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	3	67	0	0	0	0	0	0	3	7	58	1	0	0	0	0	0	1	2	67	0	0	0	0	0
Waste Collection	0	5	32	47	1	0	0	0	0	0	1	7	67	0	0	0	0	0	0	1	7	62	0	0	0	0	0	0	4	16	48	1	0	0	0	0	0	1	9	60	0	0	0	0	0
Waste Treatment	0	3	15	66	0	0	0	0	0	0	1	3	71	0	0	0	0	0	0	1	3	67	0	0	0	0	0	0	4	11	53	1	0	0	0	0	0	1	5	63	0	0	0	0	0
Landline Telephone	0	3	11	70	0	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	11	53	1	0	0	0	0	0	1	8	61	0	0	0	0	0
Mobile Telephone	0	3	14	67	0	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	11	53	1	0	0	0	0	0	1	7	62	0	0	0	0	0
Internet	0	3	15	66	0	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	6	64	0	0	0	0	0	0	4	12	52	1	0	0	0	0	0	1	8	59	0	0	0	0	0
Civil Protection	0	3	37	52	0	0	0	0	0	0	1	8	66	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	16	49	0	0	0	0	0	0	1	12	57	0	0	0	0	0
Fire	0	3	18	61	2	0	0	0	0	0	1	8	64	2	0	0	0	0	0	1	7	59	3	0	0	0	0	0	3	9	56	1	0	0	0	0	0	1	7	62	0	0	0	0	0
Medical Emergency	0	4	26	53	1	0	0	0	0	0	2	9	64	0	0	0	0	0	0	2	9	60	0	0	0	0	0	0	5	18	45	1	0	0	0	0	0	2	12	56	0	0	0	0	0
Local Police	0	3	23	58	0	0	0	0	0	0	1	7	66	0	0	0	0	0	0	1	7	63	0	0	0	0	0	0	4	16	48	1	0	0	0	0	0	1	10	59	0	0	0	0	0
Public Health	0	5	30	49	0	0	0	0	0	0	2	12	60	1	0	0	0	0	0	2	9	57	3	0	0	0	0	0	5	18	44	1	0	0	0	0	0	2	16	52	0	0	0	0	0
Green Infrastructures	0	5	17	60	1	1	0	0	0	0	5	10	57	3	0	0	0	0	0	4	5	59	2	0	0	0	0	0	4	10	54	0	0	0	0	0	0	1	7	62	0	0	0	0	0
Beaches	0	4	9	73	0	0	0	0	0	0	1	0	74	0	0	0	0	0	0	1	1	69	0	0	0	0	0	0	3	4	61	1	0	0	0	0	0	3	14	64	0	0	0	0	0
Schools	0	4	21	60	0	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	5	65	0	0	0	0	0	0	4	12	52	1	0	0	0	0	0	1	6	63	0	0	0	0	0
Gas distribution	0	3	13	68	0	0	0	0	0	0	1	4	70	0	0	0	0	0	0	1	4	66	0	0	0	0	0	0	4	10	54	1	0	0	0	0	0	1	4	64	0	0	0	0	0

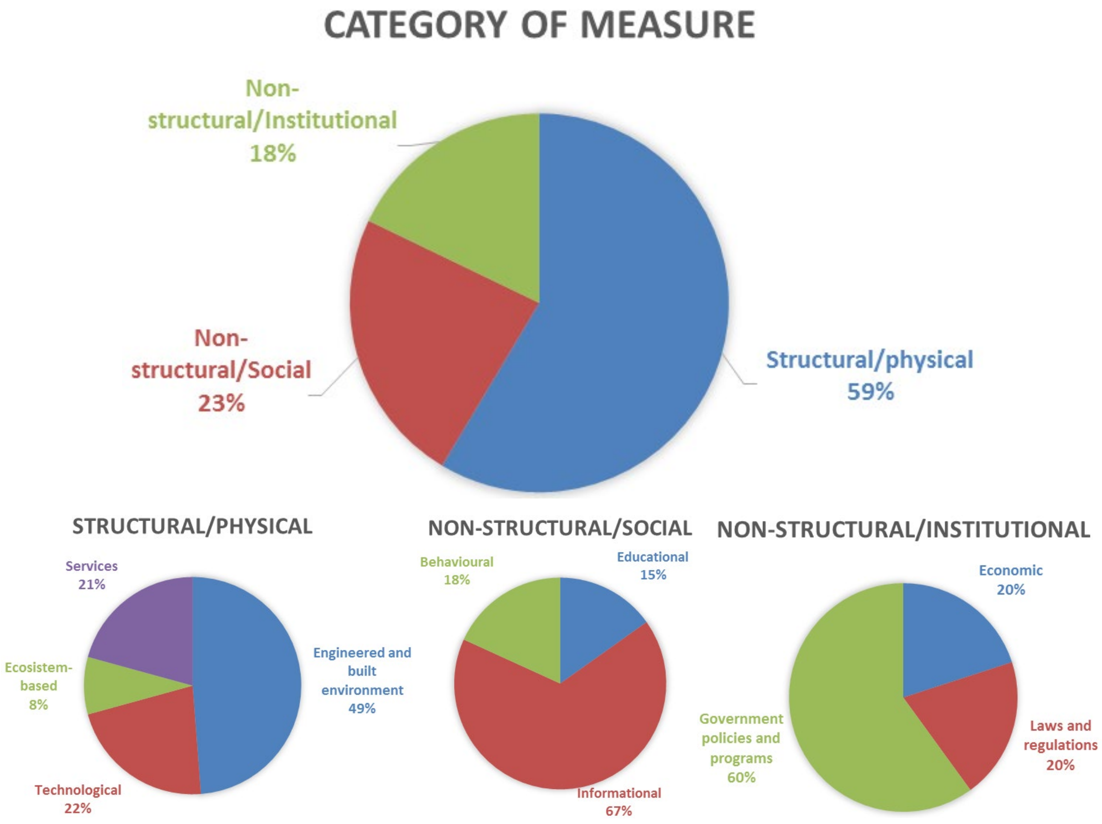


Figure 18. Distribution of the different categories of measures considered

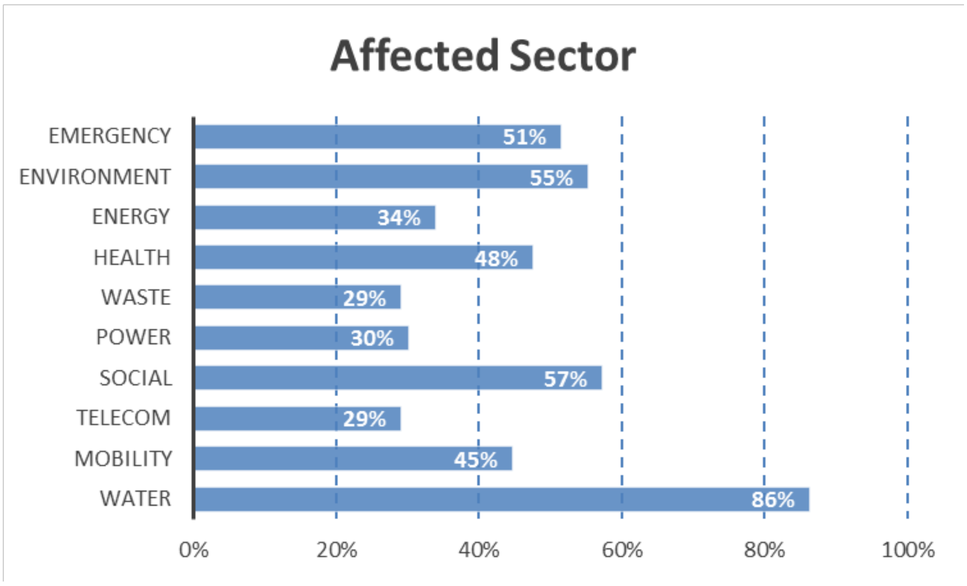


Figure 19. Distribution of percentages of the total number of measures according to the affected sector

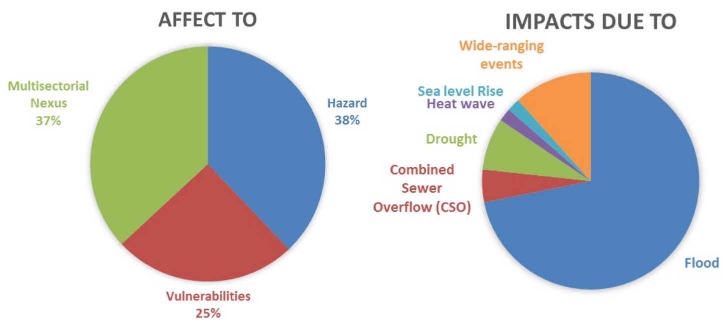


Figure 20. Distribution of measures according to the fields "affect to" and "impacts due to"

4 Conclusions

In order to bridge the city gaps (increasing the resilience), thereby improving the way to face the hazards and the related potential risks to urban services, adaptation strategies will have to be implemented. The present framework has given first a general context about RESCCUE project by describing the considered hazards, the sectors and services description together with the already known vulnerabilities (i.e. hazards to sectors) for the different sites. Afterwards, the three key variables (i.e. recovery time reduction, co-benefits, strategies estimated cost) proposed here to make decisions for the adaptation strategies selection have been described.

Furthermore, a procedure to prove the strategies effectiveness through a *post-strategies city resilience assessment* (Hazur®) (holistic approach), and through a risks re-assessment (i.e. implementation in the sectorial models) (detailed approach) has been proposed. Therefore, the selected strategies will interact not only with WP4 (HAZUR® assessment) but also with WP2 (hazard) and WP3 (vulnerability and risk).

Based on a literature review and the shared partners' knowledge, and taking advantage of the city councils contributions, a database of adaptation measures has been performed. In this framework the measures have been characterized the most comprehensively as possible by providing information (i.e. fields) based on the literature review and the city councils suggestions.

In this manner, after assessing how resilient the three cities are (Bristol, Barcelona and Lisbon) through Hazur®, different adaptation strategies may be created first and selected later to be implemented, based on the adaptation measures database. This database has been included in a decision support application (web-based platform) in order to facilitate the strategies creation, which calculates also the corresponding couple of matrices for the created strategies. Accordingly, after the strategies selection the Hazur® "what if" matrix may be modified by employing the obtained VRT matrix, and a different outcome will be obtained through a new Hazur® assessment (post strategies resilience status).

Therefore, this framework provides a way to assess how efficient a strategies selection is, by focusing on maximizing the co-benefits obtained and the reduction on the city recovery time through a new Hazur® assessment (post-strategies city resilience assessment), with the minimum possible cost. Within the upcoming deliverable D5.2 the methodology to prioritize the selected strategies will be proposed.

RESCCUE
RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

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ANNEXES

A1. Terms Glossary

Accommodation approach: The accommodate approach involves the continued occupancy and use of vulnerable zones by increasing society's ability to cope with the effects of extreme events. (source: Linham M. M. and Nicholls R. J. 2010)

Actor: A person linked to a specific action within the resilience action, but who does not participate in the resilience implementation process. (source: Hazur® terminology)

Adaptation (to climate change): The process of adjustment to actual or expected climate, and its effects. See also Autonomous Adaptation, Evolutionary Adaptation, Incremental Adaptation and Transformative Adaptation. (source: IPCC 2014a)

Adaptation assessment: The practice of identifying options to adapt to climate change and evaluating them, in terms of criteria such as availability, (co-) benefits, costs, effectiveness, efficiency and feasibility. (source: adapted from IPCC 2014a)

Adaptation measures: are specific interventions to address a specific climate risk. This can be a measure that for example

- Prevents a hazardous event from happening
- Reduces or deflects the impact of a hazardous event
- Improves recovery after a hazardous event has happened

Measures can be technical, infrastructural, but also legal, economical of social. So a measure could be building a dam, increasing the price of drinking water or raising awareness of flood risks. (Rocha *et al.*, 2017)

Adaptation Options: The array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social. (source: IPCC 2014a)

Adaptation strategies: are a collection of measures linked to specific risks and their impacts. The strategy provides a framework of which the measures are the practical outcome. A strategy consists of:

- Identification of the risks and their impacts
- Strategic goals that need to be achieved
- Measures that help achieve those goals by addressing the risks
- Implementation plan for the measures

The analysis in this phase will be based on the individual measures, but the outcome will be beneficial in developing the strategies. (Rocha *et al.*, 2017)

Adaptive capacity (or adaptability): The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. (source: IPCC 2014a)

Business Interruption: it relates to the monetary losses a business suffers as an indirect result of an impact. E.g. flooding of fabrication plant that is flooded is considered direct damage, but the reduction in the purchases of inputs, which will affect a supplier of the fabrication plant, is considered an indirect damage and as such Business Interruption.

Cascading Effects: A sequence of events in which each one produces the circumstances necessary for the initiation of the next. See also Consequence Analysis (source Allaby 2004). Or a sequence of events in which each individual event is the cause of the following event; all the events can be traced back to one and the same initial event. (source: Rome *et al.* 2015)

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. (source: IPCC 2013)

Climate Change: Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. (source: IPCC 2013)

Climate Projection: A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. (source: IPCC 2013)

Climate Model: A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties.(source: IPCC 2013)

Climate System: The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them. (source: IPCC 2013)

Co-benefits: The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefit. (source: Allaby 2004)

Consequence: The outcome of an event affecting objectives. (source: ISO/IEC 27000: 2014 and ISO 310000: 2009)

Consequence Analysis: Consequence Analysis is estimation of the effect of potential hazardous events. (source: Australian Emergency Management Glossary (1998))

Contextual Vulnerability: A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes. (source: IPCC 2014a)

Coping Capacity: The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term. (source: IPCC 2014a)

> *Further definition*: The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters. (Source: UNISDR 2009)

Critical Infrastructure (CI): An asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions. Organizations and facilities that are essential for the functioning of society and the economy as a whole. (source: European Commission: Council Directive 2008/114/EC ISO/IEC TR 27019:2013)

Critical Infrastructure (CI) Dependency: CI dependency is the relationship between two (critical infrastructure) products or services in which one product or service is required for the generation of the other product or service. (source: Rome et al 2015)

Critical Infrastructure (CI) Element: Part of a CI. It can have sub-elements. (source: Rome et al 2015)

Critical Information Infrastructure (CII): Critical information infrastructures ('CII') should be understood as referring to those interconnected information systems and networks, the disruption or destruction of which would have serious impact on the health, safety, security, or economic wellbeing of citizens, or on the effective functioning of government or the economy. (source: OECD Recommendation of the Council on the Protection of Critical Information Infrastructures C(2008)35)

Critical Infrastructure (CI) Interdependency: The mutual dependency of products or services. (Source: ACIP 2003)

Critical Infrastructure Protection (CIP): All activities aimed at ensuring the functionality, continuity and integrity of critical infrastructures in order to deter, mitigate and neutralise a threat, risk or vulnerability. (source: EC Council Directive 2008/114/EC)

Critical Infrastructure (CI) Sector: Economic sectors considered critical. (source: Rome et al 2015)

Damage classification: Damage classification is the evaluation and recording of damage to structures, facilities, or objects according to three (or more) categories. (source: UN Department of Humanitarian Affairs, 1992)

Decision: The result of making up one's mind regarding a choice between alternatives (source: Wijnmalen et al 2015)

Decision Support: The structure process of activities that support decision makers and other stakeholders in coping with and resolving problems they are faced with. (source: Wijnmalen et al 2015)

Direct Damage: relates to damage that results directly from a defined impact; for example a flood event could cause direct physical damage to an infrastructure due to the immediate physical contact of flood water with humans, property and the environment. The terms ‘loss’ and ‘damage’ are used synonymously in the literature.

Disaster: it refers to severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (Field *et al.* 2012).

Disruption: Incident, whether anticipated (e.g. hurricane) or unanticipated (e.g. a blackout or earthquake) which disrupts the normal course of operations at an organization location. (Source: ISO/PAS 22399, 2007)

Down time: it is Hazur® terminology and means the period of time during which an element (i.e. service or infrastructure) becomes inoperable or is not performing its proper function due to a certain impact (e.g. Flood, heat wave, drought or sea level rise)

Drivers: Drivers are aspects which change a given system. They can be short term, but are mainly long term. Changes in both the climate system and socioeconomic processes including adaptation and mitigation are drivers of hazards, exposure, and vulnerability. Drivers can, thus, be climatic or non-climatic. Climatic drivers include: warming trend, drying trend, extreme temperature, extreme precipitation, precipitation, snow cover, damaging cyclone, sea level, ocean acidification, and carbon dioxide fertilisation. Non-climatic drivers include land use change, migration, population and demographic change, economic development. (source: based on IPCC 2014b (SPM))

Efficiency: The good use of time and energy in a way that does not waste any. (source: http://dictionary.ca mbridge.org/dictionary/english/efficiency)

Effectiveness: The ability to be successful and produce the intended results (source: http://dictionary.ca mbridge.org/dictionary/english/effectiveness)

Ensemble: A collection of model simulations characterizing a climate prediction or [climate] projection. (source: IPCC 2013)

European Critical Infrastructure: Critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States. The significance of the impact shall be assessed in terms of cross-cutting criteria. This includes effects resulting from cross-sector dependencies on other types of infrastructure. (source: Council Directive 2008/114/EC)

Event: Occurrence or change of a particular set of circumstances. An event can be one or more occurrences, and can have several causes. An event can consist of something not happening. An event can sometimes be referred to as an "incident" or "accident". (source: ISO/PAS 22399:2007 and ISO/IEC 27000:2014)

Evolutionary Adaptation: For a population or species, change in functional characteristics as a result of selection acting on heritable traits. The rate of evolutionary adaptation depends on factors such as the strength of selection, generation turnover time, and degree of outcrossing (as opposed to inbreeding). (source: IPCC 2014a)

Exposure: The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected (source: IPCC 2014a)

Extreme Weather Event: An extreme weather event is an event that is rare at a particular place and time of year. (source: IPCC 2013)

Flood Risk: The risk associated with flood events in a certain region and in a certain time period.

Green Infrastructure: Broadly defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. Note: Green infrastructure may incorporate both landscape and water features, the latter of which may be termed 'blue infrastructure'. Other terms include 'green-blue infrastructure' and 'green and blue infrastructure'. (Source: European Commission 2013)

Grey Infrastructure: Familiar urban infrastructure such as roads, sewer systems and storm drains is known as 'grey infrastructure'. Such conventional infrastructure often uses engineered solutions typically designed for a single function. (source: Parliamentary Office of Science & Technology 2013)

Hazard: The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. The term hazard usually refers to climate-related physical events or trends or their physical impacts. (source: IPCC 2014a)

Impact Chains: Impact chains permit the structuring of cause - effect relationships between drivers and/or inhibitors affecting the vulnerability of a system. Impact chains allow for a visualization of interrelations and feedbacks, help to identify the key impacts, on which level they occur and allow visualising which climate signals may lead to them. They further help to clarify and/or validate the objectives and the scope of the vulnerability assessment and are a useful tool to involve stakeholders. (BMZ 2014)

Impact: the effect/influence of an event (naturally occurring or manmade) that results in a consequence such as causing damage and/or disruption to a service or infrastructure. An example of an impact could be a flood event causing damage to an energy substation resulting in a localised power cut. The term 'impact' refers to the broad effects that an event can have on people, to property and to the environment. These impacts can be both positive and negative, although it is common in the literature to see the term used in a purely negative sense, especially in relation to human health, where health impact assessments are conducted.

Improvement area: domain to be improved to increase the resilience of a specific urban area. For example: Improving the citizen service/Improving mobility in the coastal district of the city

Improvement project: specific action belonging to an improvement area that allows to reduce the recovery costs (political, economic, social, technological, environmental, and legal) in an urban area, thus increasing its resilience. For example: Setting up a free hotline for citizens/New roundabout in city access XY

Incident: Event that might be, or could lead to, an operational interruption, disruption, loss, emergency or crisis. (source: ISO/PAS 22399: 2007)

Incremental Adaptation: Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale. (source: IPCC 2014a)

Indirect Damage: damage induced by the direct impacts and may occur – in space or time – "outside" the event. In the context of RESCCUE it refers to the detrimental effect on a system.

Infrastructure: physical buildings and objects that provide or facilitate the distribution of a service. In the example of "Energy Supply" an infrastructure could be a power station, power lines, power substation etc., and in the context of "Health Care" an infrastructure could be a hospital, clinic, blood bank, etc.

Intangible damage: damages that cannot be expressed in monetary values, for example the loss of life or the deterioration of health as a result/consequence of an impact.

Intensity: The quality of being intense. The measurable amount of a property, such as force, brightness, or a magnetic field. (source: Oxford English Dictionaries https://en.oxforddictionaries.com/definition/intensity)

Interdependence: relationship between different services or infrastructures that is given when one service or infrastructure (donor) fails and makes fail another one (the receptor). [Example: waste water treatment plant X fails if Y power transformer fails.]. (source: Hazur® terminology)

Likelihood: The chance of a specific outcome occurring, where this might be estimated probabilistically. (source: IPCC 2014a)

Maladaptation: Actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future. (source: IPCC 2014a)

Mitigation: The lessening of the potential adverse impacts of physical hazards (including those that are human-induced) through actions that reduce hazard, exposure, and vulnerability. (source: IPCC 2012)

Operators Group: Group formed by the steering group and the management of significant operators of infrastructure and services in the territory. (source: Hazur® terminology)

Passive Measure: It is a type of measure which does not use energy once it has been implemented. It is normally referred to adaptation measures for buildings indoor environments. (source: Van Hooff et al 2014)

Probability: Measure of the chance of occurrence expressed as a number between 0 and 1 where 0 is impossibility and 1 is absolute certainty. (Source: ISO Guide 73:2009). Or the likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible outcome and 1 indicating an outcome is certain. (source: Australian Emergency Management Glossary (1998))

Probabilistic Climate Projections: These are projections of future absolute climate that assign a probability level to different climate outcomes. This projection provides an absolute value for the future climate (as opposed to giving values that are relative to a baseline period) that assign a probability level to different climate outcomes. (source: Adapted from the UK Met Office 2014)

Protection approaches: A protection approach involves defensive measures and other activities to protect areas against flood risk. The measures may be drawn from an array of "hard" and "soft" structural solutions. (source: Linham M. M. and Nicholls R. J. 2010)

Player: A person linked to the management or the operation of a service or infrastructure in an urban area and engage in the resilience implementation process, including politicians, municipal technical staff and service operators. (source: Hazur® terminology)

Recovery: The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors. (source: UNISDR 2009)

Recovery time: When an extreme event strikes a city a decrease of functionality occurs. Following a gradual recovery of its functionality happens, until it is fully functional after a time increment, the recovery time (Bruneau et al., 2003). One of the Hazur® outputs, resulting from a simulation, within the impact report generated, is the average foreseen recovery time.

Redundancy: Service of infrastructure that can replace or can be replaced with another service or infrastructure. [Example: a power transformer able to replace another power transformer of the same urban area, a hospital that can accept people that cannot go to their district health center.]. (source: Hazur® terminology)

Reliability: Property of consistent intended behaviour and results. (source: ISO/IEC 27000:2014)

Resilience: The capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (Arctic Council, 2013) (source: IPCC 2014a)

Further definition: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. (Source: UNISDR 2009)

Responder: Technical or human equipment to mobilize in case of crisis. [Example: a power generator, the police, a psychologist team.]. (source: Hazur® terminology)

Retreat approaches: In the measures context, the retreat approach refers to planned withdraw from the coast or the often inundated areas, rather than an unplanned or forced retreat which is also potentially possible in the face of sea level rise and climate change. (source: Linham M. M. and Nicholls R. J. 2010)

Risk: the probability of harmful consequences — casualties, damaged property, lost livelihoods, disrupted economic activity, and damage to the environment — resulting from interactions between natural or human-induced hazards and vulnerable conditions.

Scenario: A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g. rate of technological change, prices) and relationships. (source: IPCC 2013)

Sector: A part or division, as of a city or a national economy. (Source: American Heritage® Dictionary of the English Language)

Sensitivity: see **Susceptibility**

Service: Group of activities with the aim of meeting the needs and ensuring the quality of life of the inhabitants of a territory. (source: Hazur® terminology)

Social Infrastructure (Institutional): The social infrastructure includes the humans, organizations and governments that make decisions and form our economy as well as our institutions and policies. (source: Chappin and van der Lei 2014)

Social Infrastructure (Physical): Schools, hospitals, shopping or cultural facilities. (source: unpublished working glossary of UP KRITIS and BSI, 2014)

Source Control Measures: Source control measure means any stormwater management practice designed to reduce and/or slow the flow of stormwater into a combined sanitary and stormwater sewer or a separate stormwater sewer, including, but not limited to, any such practices commonly referred to as Low Impact Development or Best Management Practices. (source: New York City Administrative Code-Section 24-526. 1: Sustainable Stormwater Management)

Stakeholder: Person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity. Note: A decision maker can be a stakeholder. (source: adapted from: ISO 31000:2009)

Steering Group: Group constituted almost entirely of senior administration officials with authority over essential services and infrastructure to ensure resilience in the territory being studied. Responsible for defining the significant operators, territorial resilience objectives, the key processes, and to make major impacts that may occur. (source: Hazur® terminology)

Strategic Group: Group of senior political and managerial leadership of public organizations. It will bring conviction and political action to the project validating performances from a strategic standpoint. (source: Hazur® terminology)

Stressors: Events and trends, often not climate-related, that have an important effect on the system exposed and can increase climate related risk. (Source: adapted from Oppenheimer *et al.* 2014: p. 1048).

Susceptibility: (within RESCCUE susceptibility and sensitivity, will act as synonyms) the degree to which the system is affected, depending on the own intrinsic characteristics of its exposed elements within the area in which hazardous events may occur. These intrinsic properties include, for instance, the physical characteristics of exposed elements (service, infrastructures, etc.), the economic and social context of the community, etc. For floods, for instance, important capacities are the awareness and preparedness of affected people and the existence of mitigation measures to reduce the effects of the hazards, like warning systems and emergency plans (Rocha *et al.*, 2017).

Tangible damage: the monetary damage that has occurred as a result of an impact.

Transformative Adaptation: Adaptation that changes the fundamental attributes of a system in response to climate and its effects. (source: IPCC 2014a)

Uncertainty: A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. (source: IPCC 2014a)

Urban (Urban Area): Urban 'is a function of (1) sheer population size, (2) space (land area), (3) the ratio of population to space (density or concentration), and (4) economic and social organization.' (Source: Weeks 2010). Or the OECD-EU classification identifies functional urban areas beyond city boundaries, to reflect the economic geography of where people live and work. Defining urban areas as functional economic units can better guide the way national and city governments plan infrastructure, transportation, housing and schools, space for culture and recreation. (source: OECD 2012)

Urban Critical Infrastructure: An asset, system or part thereof located in an urban area which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in an urban area as a result of the failure to maintain those functions. (source: adapted from EC Council Directive 2008/114/EC)

Urban Critical Infrastructure System: Urban critical infrastructure from a systemic viewpoint. It is part of the urban system and simultaneously part of the national critical infrastructure system. (source: Rome et al 2015)

Urban System: System of urban areas (Urban settlements from a systemic viewpoint) (source: Rome et al 2015)

Vulnerability: the propensity of exposed elements (such as human beings, their livelihoods and assets) to suffer adverse effects when impacted by hazard events. Vulnerability is related to predisposition or capacities that favour, either adversely or beneficially, the adverse effects on the exposed elements. Vulnerability refers to exposure, susceptibility and resilience (Rocha *et al.*, 2017).

Vulnerability Index: A metric characterizing the vulnerability of a system. A climate vulnerability index is typically derived by combining, with or without weighting, several indicators assumed to represent vulnerability. (source: IPCC 2014a)

What if matrix: it is a matrix which gathers all down times of all services or infrastructures (i.e. rows) according to different impacts (i.e. columns). The rank of the matrix will depend on the services/infrastructures and impacts considered when developing the city model through Hazur®.

Wicked Problem: A problem that is categorized by a great number of uncertainties. These include: on the stakeholders involved, the boundaries of the problem, long term organisational developments and responsibilities, amongst others. (Source: adapted from Wijnmalen et al 2015. Please also see Rittel and Webber 1973)

A2. Summary of projects related to climate adaptation measures for specific sectors

In this annex, a table to summarize the main information of the different reviewed project is offered in order to ease the access to further information if required.

Table 7. Summary of reviewed projects

Project	Sector	State	Coordinator/Responsible/Author	Link
Collaborative Research on Flood Resilience in Urban areas (CORFU) (2010-2014)	Water cycle	Finished	The University of Exeter (United Kingdom)	http://www.corfu7.eu/
PREPARED "Enabling Change" (2010-2014)	Water cycle	Finished	KWR WATER B.V. (The Netherlands)	http://www.prepared-fp7.eu/
Preparing for Extreme And Rare events in coastaL regions (PEARL) (2014-2018)	Water cycle	Ongoing	UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION –UNESCO (France)	http://www.pearl-fp7.eu/
Climate RESilient cities and Infrastructures (RESIN) (2015-2018)	Water cycle	Ongoing	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO (The Netherlands)	http://www.resin-cities.eu/home/
Bringing INnovation to onGOing water management – A better future under climate change (BINGO) (2015-2019)	Water cycle	Ongoing	LABORATORIO NACIONAL DE ENGENHARIA CIVIL (Portugal)	http://www.projectbingo.eu/
PLAtform for Climate Adaptation and Risk reDuction (PLACARD) (2015-2020)	Water cycle	Ongoing	FCIENCIAS.ID - ASSOCIACAO PARA A INVESTIGACAO E DESENVOLVIMENTO DE CIENCIAS (Portugal)	http://www.placard-network.eu/
BRIdges the GAp for Innovations in Disaster resilience (BRIGAID) (2016-2020)	Water cycle	Ongoing	TECHNISCHE UNIVERSITEIT DELFT (The Netherlands)	http://brigaid.eu/
FLOOD-CBA (2013-2015)	Water cycle	Finished	Sigma Consultants Ltd (Greece)	http://www.floodcba.eu/
Balancing energy production and consumption in energy efficient smart neighbourhoods (e-balance) (2013-2017)	Power	Finished	IHP GMBH - INNOVATIONS FOR HIGH PERFORMANCE (Germany)	http://ebalance-project.eu/
Improving the Robustness of urban Electricity Networks (IRENE) (2014-2017)	Power	Ongoing	AIT Austrian Institute of Technology	http://ireneproject.eu/
Realising European ReSiliencE for CritIcaL INfraStructure (RESILENS) (2015-2018)	Power	Ongoing	FUTURE ANALYTICS CONSULTING LIMITED (Ireland)	http://resilens.eu/

Project	Sector	State	Coordinator/Responsible/Author	Link
Smart Mature Resilience for more resilient cities in Europe (SMR) (2015-2018)	Power	Ongoing	TECNUN. University of Navarra (Spain)	http://smr-project.eu/home/
PORLisboa: Improved Public Lighting	Power	Finished	Camara Municial de Lisboa	https://goo.gl/T1SqxN
PPEC Lisboa: LED in Traffic Lights	Power	Finished	Lisboa E-Nova and EMEL Agencia de energia e ambiente de Lisboa	https://goo.gl/88QpTE
Lisbon: Energy Efficient use in Public Lightning	Power	Finished	Lisboa E-Nova and EMEL Agencia de energia e ambiente de Lisboa	http://lisboaenova.org/index.php
Risk Analysis of Infrastructure Networks in response to extreme weather (RAIN) (2014-2017)	Mobility	Ongoing	Trinity College Dublin	http://rain-project.eu/
Climate Change and Everyday Mobility (CLIMAMOB) (2015-2018)	Mobility	Ongoing	The University of Oxford's Transport Studies Unit (TSU)	https://goo.gl/Cv2AAt
Providing Transport Services Resilient to Extreme Weather and Climate Change (2015)	Mobility	Finished	Transport for London (TfL)	https://goo.gl/nfa9xE
Adaptation of transport to climate change in Europe, Challenges and options across transport modes and stakeholders (2014)	Mobility	Finished	European Environment Agency	https://goo.gl/QLRN1P
Mobi-E: Electric Mobility in Lisbon	Mobility	Finished	Lisboa E-Nova and EMEL (Lisbon Mobility and Parking Municipal Company)	https://goo.gl/YcUyCt
Guide to Climate Change Adaptation in Cities. The World Bank Group report (2011)	Waste	Finished	The International Bank for Reconstruction and Development/ The World Bank	https://goo.gl/zRDQUr
Increasing the climate resilience of waste infrastructure. Adapting to Climate Change, DEFRA report (2012)	Waste	Finished	AEA Technology	https://goo.gl/ihUncQ
Climate Change Resilient Development (CCRD) project. U.S. Agency for International Development technical report (USAID) (2012)	Waste	Finished	Global Climate Change (GCC) Office	http://www.ccrdproject.com/
Waste management options and climate change (2001)	Waste	Finished	AEA Technology	https://goo.gl/dCdygM
Food Surplus and Its Climate Burdens (2016)	Waste	Finished	Ceren Hiç, Prajal Pradhan, Diego Rybski, and Jürgen P. Kropp	https://goo.gl/2xVN48

Project	Sector	State	Coordinator/Responsible/Author	Link
			Potsdam Institute for Climate Impact Research Department of Geo- and Environmental Sciences	
Adapting Waste and Recycling Collection Systems to the Changing Climate (2011)	Waste	Finished	Waste and Resources Action Programme (WRAP)	https://goo.gl/sKjEHa
LIFE PAYT – Tool to Reduce Waste in South Europe (2016-2019)	Waste	Ongoing	Polytechnic Institute of Coimbra	http://www.life-payt.eu/pt/
UrBAN-WASTE (2016-2019)	Waste	Ongoing	GOBIERNO DE CANARIAS	http://www.urban-waste.eu/
Climate Risks Study for Telecommunications and Data Center Services (2014)	Telecom	Finished	The US General Services Administration (GSA)	https://goo.gl/up5fem
Climate Change: the Contribution of Telecommunications (2009)	Telecom	Finished	Ewan SUTHERLAND Research Associate, LINK Centre	https://goo.gl/CKJSTL
Climate Change Adaptation (2010)	Telecom	Finished	Ofcom	https://goo.gl/S3mfZ2

A3. Hazur® Approach

A3.1. Resilience Thinking: A Systemic Approach

Opticits has built up the HAZUR® approach taking into account the different concepts related to resilience, different visions of the city, industrial methodologies, business continuity procedures, etc. Some of them are described here below.

Since every single city was born and has grown in a different geographic, social and cultural environment, the needs and possibilities in each urban centre are different. However, all cities have similarities that can be studied to create effective models for their study and understanding. Over the years, several bodies have tried to create an "anatomy of the city", but always under a theoretical framework and with an academic sense.

A metaphor that may be used to understand the HAZUR® approach is that the city is like a human body. In this body, the different services would be the different systems (nervous system, circulation system, muscular system, etc.), the different infrastructures would be the different organs (heart, lungs, kidneys, etc.), and people would be the blood that keeps the system of systems, which is the city, alive.

Opticits has also taken into account industrial methodologies as **HazOp** (Hazard and Operability) and **HAZID** techniques (HAZard IDentification studies) (Fontanals *et al.*, 2014), Strategical Analysis from the Business Management discipline and Industrial Security methods, and adaptations from the Delphi method (Scott, 2001).

Moreover, from the term **social resilience** defined by UNISDR, it will be talked about Urban Resilience (Dickson *et al.*, 2012). An acronym that simplifies the understanding of the word Resilience applied to an urban environment has been proposed: PREWIRRL (**Prepare - Withstand - Respond- Recover - Learn**) from crisis, meaning that urban services are developed always in the face of crisis. Urban resilience must be understood as a property of an urban system that indicates the ability of infrastructures and services to PREWIRRL and overcome regular crisis.

Finally, the studies concerning the interactions between urban subsystems have concluded that most of the disturbances and failures occur or are spread by technical and transport networks or infrastructures (Lhomme et al, 2011 & 2013). This leads us to argue that poorly controlled interrelations between networks lead to additional vulnerabilities. Given these interdependencies and the resulting cascading effects, which make the recovery and reconstruction process more difficult and slower during and after a disturbance, the concept of resilience centred on the concept of **functional recovery** is developing. Applied to the urban system, the concept can be described as "on one hand the ability of a city to function while some components of the urban system are disrupted, on the other the city's ability to rebuild (recover or adapt its functions) following this disturbance" (Lhomme *et al.*, 2013).

In short, it can be stated that with the urban metabolism and services supply resilience management start the short-term resilience enhancement, monitoring and having an in-time control on the complex network of infrastructures. Also with the strategic planning it is fostering the critical long-term resilience, evaluating who– where – when urban system need more investments. **Urban metabolism and service supply can only be managed in an integrated way**.

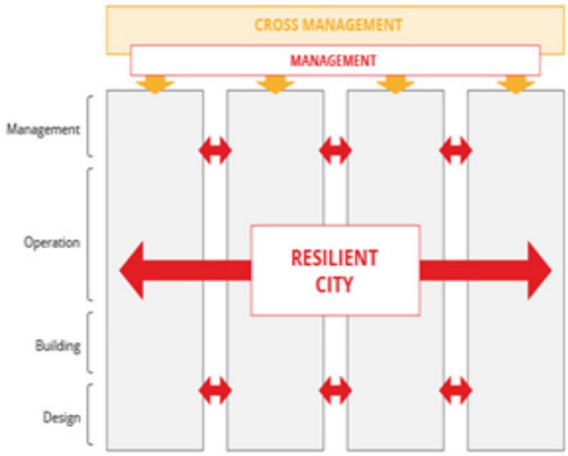

Figure 21. Cross-cutting approach of the city management

Considering all previous statements, and the special importance of interdependences within an urban system, Opticits has developed **HAZUR®, a method and software designed to support the assessment, implementation and management of cities' resilience**.

The urban resilience assessment with HAZUR® (and the HAZUR® Assessment software module) proposes an analysis from main resilience strategy to operation of urban services resilience by means of detecting **adaptation strategies** helping to understand the city needs and the necessity for establishing Resilience Plans or Resilience Action Plans.

The management of urban resilience with HAZUR® (and the HAZUR® Manager software module) aims at implementing and operating controls and measures for managing the municipality overall capability to manage the city as a "System of Systems" and to face any kind of disruptive incident or impact, bounce back and learn from this experience. HAZUR® Manager emphasizes the importance of monitoring and reviewing the performance and effectiveness of the urban system based on a continual improvement vision by using simulation and data monitoring to engage city stakeholders and apply the "Plan-Do-Check-Act" (PDCA) model for cities.

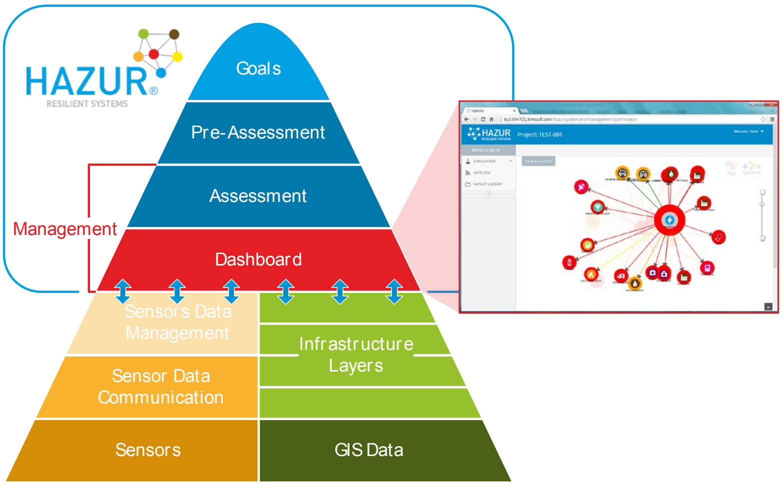

Figure 22. Diagram showing the global HAZUR® approach

HAZUR® Assessment allows performing a systemic analysis to build up a systemic model, which includes the functional interdependences. This is possible thanks to the collaboration with all city actors and to the collection of functional data. HAZUR® merges a qualitative and quantitative approach in order to help city stakeholders or the Chief Resilient Officer. The objectives are indeed to assess urban services and infrastructures vulnerability, to build scenarios and simulations once the interdependency map has been created. At the same time, HAZUR® allows the construction of a model based on the physical data. Finally, HAZUR® evolves into a more federative tool in the sense that collects information from other sources (sensors, spatial areas, etc.).

The HAZUR® software is a SaaS (software as a service) customizable in terms of urban system size and complexity and merges qualitative and quantitative data. It supports the HAZUR® methodology as follows:

Figure 23. HAZUR® methodology and software

The application of HAZUR® in cities has demonstrated that managing urban services reliability through service interdependency analysis, vulnerability reduction and resilience improvement indirectly provides the basis for a systemic and strategic infrastructure and urban planning (Fontanals *et al.*, 2014).

HAZUR® implementation process was improved thanks to the collaboration with city managers from different cities (Barcelona, Tremp, La Garrotxa, Sant Cugat…) and more recently the methodology has been improved to help city managers to apply the New Urban Agenda principle and the Sustainable Development Goals (mainly goal 11) and to help improving the city management systems and the knowledge of city risks in order to facilitate the access to new financing models for cities.

HAZUR® is aligned with the approaches from Disaster Risk Reduction platforms, multilateral organizations (UNISDR, UN-Habitat), 100 Resilient Cities, city technology visions ("Smart City" concept) and academic research about resilience of urban systems.

A3.2. HAZUR® Assessment

As explained, the HAZUR® Assessment methodology is a systemic and collaborative approach, also inspired by the research work of Marie Toubin (Toubin et al, 2014) at the EIVP (Ecole des Ingénieurs de la Ville de Paris) and based on the knowledge and the experience of the local stakeholders and networks operators through workshops led by experts in resilience. These workshops involve managers (identified as players) of the urban areas implicated in the city resilience.

The first part of the workshops is devoted to explain the above-mentioned background, with the idea of giving the participants some information about the research project (Fontanals *et al.*, 2012). Workshops have been designed in HAZUR® with the specific purpose to obtain information. This information is obtained using the Delphi method (Scott, 2001): a repetitive process searching a consensus based on the discussion among experts. In fact, HAZUR® approach was originally developed by means of HAZID techniques (Hazard Identification Studies) and methodologies of Strategical Analysis from Business Management discipline. Concretely with the different steps of the assessment process, city stakeholders work structurally to produce data according to the proposed HAZUR® method. These qualitative data combined with spatial and quantitative data from urban services (sometimes open data) are captured and introduced or integrated in the HAZUR® software tool.

The modules included in the HAZUR® Assessment module that will be used to assess urban resilience using the HAZUR® methodology are presented in Figure 24.

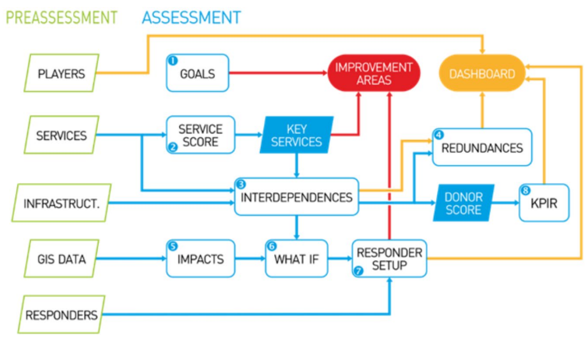

Figure 24. HAZUR® Assessment phase

To apply this methodology, the HAZUR® Assessment module will be fed with critical information about urban services, infrastructure, taxonomy, people and organizations in charge, environmental and climatic conditions, etc. collected in forms, personal interviews and/or workshops. Information is geo-located and identified with a detailed typology.

A detailed mapping of the city using data from existing databases or collected by forms or personal interviews will be performed. Data will then be validated with personal interviews or workshops: identification of urban actors, both from public organization and private companies supplying services to the city, identification and prioritization of urban services and infrastructures, identification of responders (human and technical equipment needed to mitigate the effects of impacts). City data will be then analysed in order to: identify interdependences between services and infrastructures, identify existing redundancies, identify impacts and consequences into the urban system (**What If matrix**), and identify cascade effects.

One of the results of this assessment process is the interdependences matrix, which computes and displays all the interdependences between the different services or infrastructures, and the level of gravity and the level of autonomy.

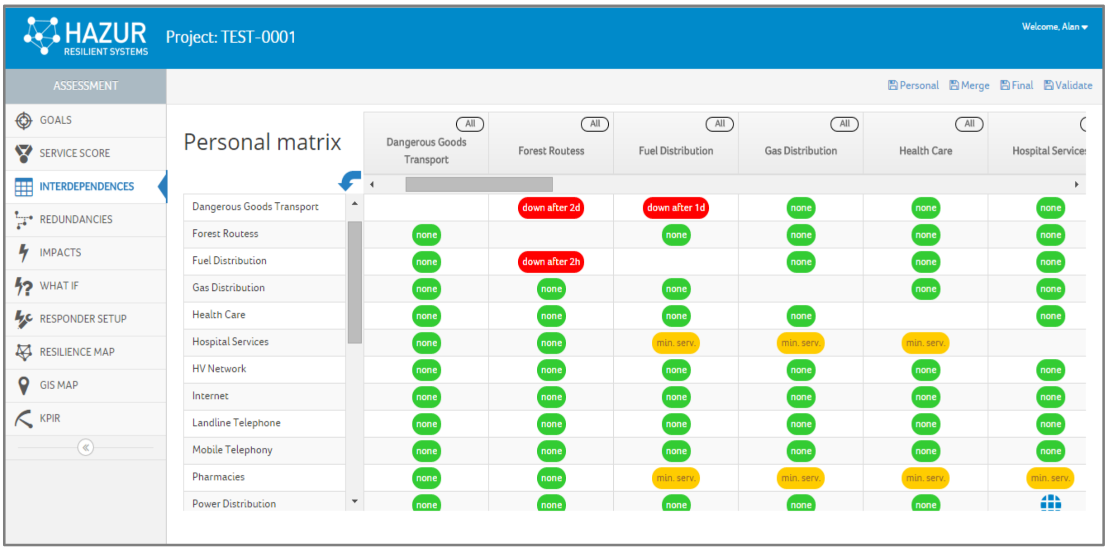

Figure 25. The interdependences matrix shows the interdependences between services/infrastructures

Thanks to the interdependence matrix, it can be visualized an interdependence map, called "Resilience Map" that displays the vulnerability and resilience of the infrastructure networks. Interdependences can also be shown on a GIS.

This map can be then used to obtain recommendations for the city managers about how to handle, prioritize and manage the resilience of technical networks and continuity of services. In fact, HAZUR® can visualize interdependences and also cascading effects, but also simulate them allowing both scenario building and strategic project planning in order to foster resilience for the benefit of citizens and economic activities in the city. The HAZUR® Assessment can thus enable a cross-functional visualization of city services; improvements in the integrated management of infrastructures, performance and continuity of urban services; protection against potential climate, natural or technical impacts; improvement of the cooperation between operators; but also detection of **adaptation strategies**.

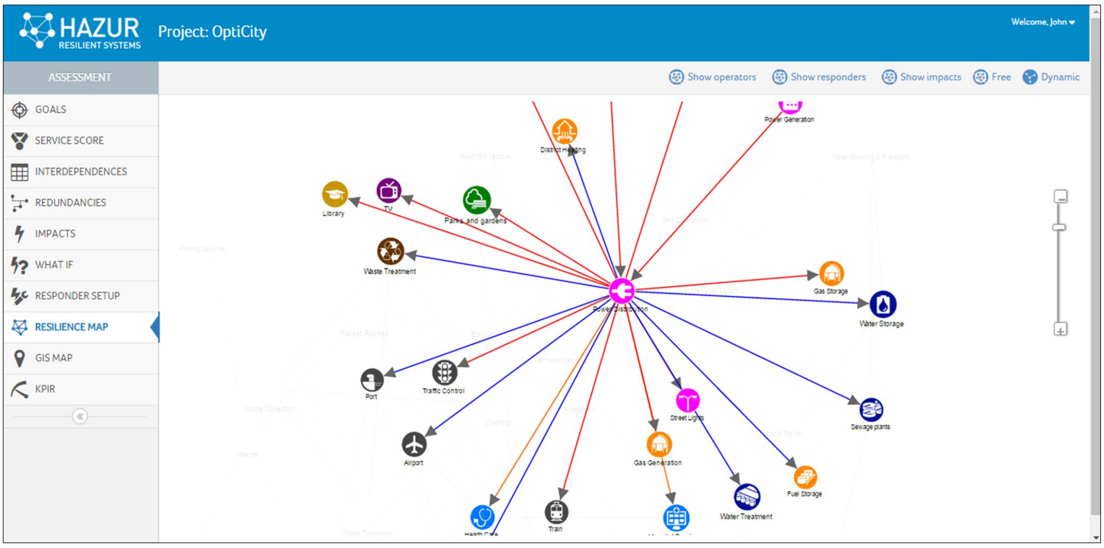

Figure 26. The "Resilience Map" shows the interdependences between services or infrastructures

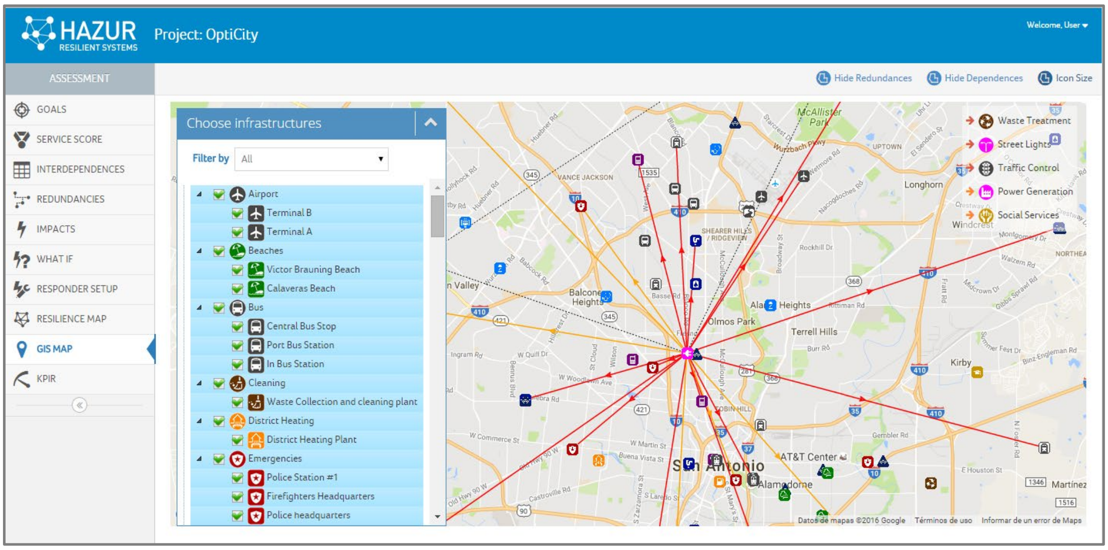

Figure 27. The GIS version of the "Resilience Map" shows the interdependences between geo-located infrastructures

According to the detailed analysis of the city anatomy and its vulnerabilities, the urban resilience strategy (or Resilience Plan) will be drafted. The Resilience Plan establishes the urban resilience strategies. It includes a prioritization of the **adaptation strategies** for resilience and its action plan and schedule. It may also include recommendations on sensors implementation or on Key Performance Indicators of Resilience (also known as KPIR, which are variables o variable sets related to critical infrastructures).

A3.3. HAZUR® Manager

After the assessment, and following the recommendations of the Resilience Plan on composition of the resilience boards, **adaptation strategies** and schedule, resilience boards meeting will be organized in order to engage in the continuous process of improving resilience. Additionally, HAZUR® software is switched into the Manager mode.

The continuity and optimized strategic planning of urban services and infrastructures are possible thanks to the monitoring and simulation capabilities of HAZUR®. Following the recommendations of the Resilience Plan, HAZUR® can be fed with the selected sensor information or other Key Performance Indicators for resilience from key infrastructures, community information from citizens, information from the control centre databases, and GIS data, thus allowing real-time monitoring of impact, urban services and infrastructures as well as the simulation on how impacts affect the city. The output of this simulation is the impact report generated by HAZUR, which includes impact area and description, affected services and infrastructures, average foreseen recovery time, contact person and other relevant data.

HAZUR® Manager can be used as a City Resilience Office tool to manage urban services, enabling anticipation of potential cascading effects, improvement of the cascading effects management, prioritization of investments and improvement of infrastructures, bridging GIS and complex information flows within the policy making and urban management decisions and processes, daily incidences management, and operational costs optimization.

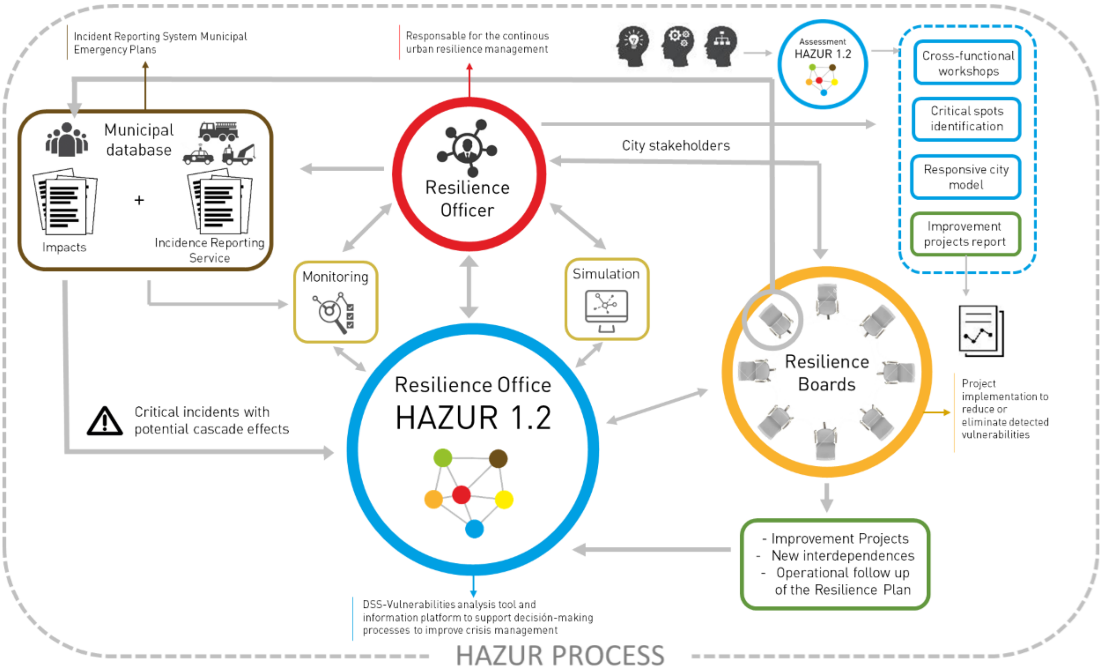

Figure 28. Urban Resilience Office according to HAZUR® continuous improvement approach