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Communication

Resilience to Cope with Climate Change in Urban Areas—A Multisectorial Approach Focusing on Water—The RESCCUE Project

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Abstract: The RESCCUE Project is an H2020 research project that aims to help cities around the world to become more resilient to physical, social, and economic challenges, using the water sector as the central point of the approach. RESCCUE will generate models and tools to bring this objective to practice, while delivering a framework enabling city resilience assessment, planning and management. This will be achieved by integrating software tools, methods, and new knowledge related to the detailed urban services performance into novel and promising loosely coupled models (integrated models), multi-risk assessment method, and a comprehensive resilience platform. These tools will allow urban resilience assessment from a multisectorial approach, for current and future climate change scenarios, including multiple hazards and cascading effects. The RESCCUE approach will be implemented in three EU cities (Barcelona, Bristol, and Lisbon) and, with the support of UN-Habitat, disseminate their results among other cities belonging to major international networks. The aim of this paper is to present the main goals of this project, as well as the approach followed and the main expected results after the four years of implementation, so other cities around the world can use the RESCCUE approach to increase their resilience.

Keywords: urban resilience; climate change; urban services; water cycle; adaptation; disaster risk management

1. Introduction

We already live in a world of cities, and that trend will continue in the future. Today, 54% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050 [1]. Moreover, climate change will cause pressures and uncertainties that will pose challenges to the society, economy, and environment. In this case, focusing on the impacts on the urban living [2], this can affect basic urban services, such as water or energy supply, making the city capacity of continuously

functioning crucial for most part of world population. As the United Nations stated, managing urban areas has become one of the most important development challenges of the 21st century [1].

According to UN-Habitat [3], urban resilience refers to the ability of human settlements to withstand and to recover quickly from any plausible hazards. Resilience against shocks and stresses not only refers to reducing risks and damage from disasters (i.e., loss of lives and assets), but also the ability to quickly bounce back to a stable state, the ability to adapt and transform towards sustainability. While typical risk reduction measures tend to focus on a specific hazard, leaving out risks and vulnerabilities due to other types of perils, resilience adopts a multiple hazards approach, considering all types of plausible climate-related threats.

Cities face a growing range of adversities and challenges in the 21st century, and increasing urban resilience is the only way to survive and adapt to the coming shocks and stresses that may occur [4]. Due to climate change, critical disruptions occur too often in cities around the world. On the other hand, urban areas are complex systems that cannot be understood by sectorial and disciplinary approaches alone [5]. In this context, the RESCCUE (RESilience to cope with Climate Change in Urban arEas—a multisectorial approach focusing on water) project aims to assess current and future resilience (related to future climate change scenarios) through a multisectorial approach taking water sector as the focus. Climatic drivers and pressures affecting the urban water cycle, such as droughts or heavy rains, can produce critical direct impacts on strategic urban services (water supply, wastewater and stormwater drainage, wastewater treatment, solid waste, telecommunication, energy supply, transport, etc.) and cause cascading collateral impacts on other services. Given the interdependencies existent between the several city services, RESCCUE focuses on the cascading failures that involve several urban functions [6]. The electric blackout coinciding with drought and transport situation that Barcelona suffered in July 2007 is a clear example of these types of emergencies. Barcelona was immersed in a worrying drought situation (that was later worsened until it ended in 2008) that had negative impacts in the energy sector, as hydroelectric power generation was at minimum due to the low water levels in upstream reservoirs [7]. On the other hand, the regional railways collapsed due to high-speed train construction works. This already critical situation was brought to the limit when the electric blackout occurred at the height of summer. This specific crisis had enormous impacts at social and economic levels that lasted the whole summer in the case of the electric system deficiencies. The impact on the city image and brand at international level (because all this was occurring during the high tourist season), is difficult to quantify. Tourism has such an important role in Barcelona's economy (generating incomes of 37 M €/day with 7.9 M tourists/year [8]), that such episodes must be minimized, because the impacts could be even larger due to future impacts that climate change might pose.

In Lisbon, the lack of drainage capacity generates a lot of cascading effects to other services that are affected by the surface water flows. As an example, during the floods that affected Praça da Figueira in 2003, the electrical substation from that square and the secondary substation of Rossio were flooded, implying cuts in other services such as street lighting, traffic lights, some telecommunications that depend directly to the distribution grid and other consumers. After this event, it was necessary to implement some measures. In the case of substation of Praça da Figueira, it was re-built with a fence surrounding the ventilation surface openings and installing an extra water extraction pump. Another example of cascading effects on Lisbon occurred in December 2017, when a windstorm caused the fall of trees, tree branches and leaves, generating cascading effects on urban drainage due to obstruction of components, and cascading effects on transport system, causing road and rail traffic disturbance and interruptions.

In Bristol, tidal floods occur in a recurrent basis due to the proximity of the city to the Bristol Channel. These floods generate a series of cascading effects of all kinds, being the most common the closure of streets and roads. For example, in January 2014, tidal flooding during rush hour led impediment of traffic flow along the Portway (one of the major traffic routes through the city), creating circulation problems that lasted for hours.

All this is precisely what motivated the several partners from the RESCCUE consortium to join forces to help cities increase their resilience. In this paper, the reader will be able to understand the goals, methodology and main expected results of the EU H2020 RESCCUE Project.

2. Materials and Methods

2.1. The RESCCUE Project

The Project RESilience to cope with Climate Change in Urban arEas—a multisectorial approach focusing on water (RESCCUE—www.resccue.eu) aims to help cities around the world to become more resilient to physical, social, and economic challenges. More precisely, RESCCUE will generate models and tools to bring this objective to practice and make these tools available to be deployed to different types of cities, with different climate change pressures. RESCCUE will also assist cities preparing their resilience action plans by developing guidance materials and plan templates. The consortium is led by Aquatec—SUEZ Advanced Solutions, and consists of a total of 18 partners with the three city councils of the research sites (Barcelona, Bristol and Lisbon), the United Nations agency UN-Habitat, several urban services companies, research centers, universities and SMEs (Small and Medium Enterprises), all of them with a key role on resilience management in the three research sites.

RESCCUE aims to assess current and future resilience considering future climate change scenarios. Climatic drivers and pressures may affect several urban services and generate cascading effects, impacting other services. Urban services managers generally use detailed sectorial models to simulate the behavior of their systems for specific scenarios, but they do not have the knowledge and holistic tools to predict the consequence of these scenarios on other urban services in an integral way.

Urban systems can be made more efficient through greater infrastructure interconnectedness [9]. This is the reason RESCCUE will tackle this issue by analyzing in detail different urban systems, with the water system (water supply and drainage systems) as the center of this assessment and identifying the relations of this sector with other services. In addition, energy and transport are crucial as they are donor services that support other city services, but solid waste, green infrastructures, receiving water bodies and telecommunication must not be forgotten given the interdependencies that exist with the other services and the services that they provide to the citizens.

The RESCCUE objective is to produce a set of models and tools to analyze urban resilience based on a multisectorial approach that overcomes current difficulties related to lack of information integration of the different urban services. To interconnect the several sectorial models, the project will take advantage of the existent HAZUR® tool and methodology, developed by Opticits (Barcelona, Spain) [10] to make it the basis of further developed software able to perform the assessment, management and planning of urban resilience in an integral way, assessing the interdependencies and analyzing the several cascading effects (which will be further studied by coupling several sectorial models such as urban drainage and sea water quality models).

The three cities included as pilot sites (Barcelona, Lisbon, and Bristol) will be the validation platforms of the improved tool, where integrated analyses of urban resilience will be performed during the last phase of the project. More information about these three research sites will be given in the following sections.

As indicated by the project title, the RESCCUE project will put more emphasis on the water sector. This approach has been taken due to the importance of the water sector in the correct functioning of a city, as it provides basic services to the population and many other services. The three pilot cities had already identified water-related risks as crucial in their hazard analysis. Therefore, resilience of the urban water cycle will be thoroughly analyzed accounting for the interactions in within, and between the water cycle and the rest of critical sectors.

Due to the complexity of urban areas, the RESCCUE project goes beyond conventional approaches to "build and improve urban resilience" delivering a forward looking, multi-scale, multisectorial and multi-hazard methodology. Relevant stakeholders and urban service managers that recognize the

complexities and unique value of cities and the inherent interdependencies of each part of an urban system will be involved.

This paradigm is a strong point of the RESCCUE project and consortium members. In fact, all the research sites (Barcelona, Bristol and Lisbon) are members of the "100 Resilient Cities" organization pioneered by The Rockefeller Foundation with a strong commitment for the resilience building through the funding of specific measures, such as, supporting the role of the Chief Resilience Officers (CRO) of the selected cities or providing training and materials to the cities.

At local level, resilience measures are contained in a Resilience Action Plan (RAP) executed by city resilience offices led by a CRO. This innovative new role (generally a person of the city government), recognized by Rockefeller Foundation and UN-Habitat, is responsible to ensure resilience building and will also oversee the development of the RAP and be part of a learning network with other CROs as representatives of the 100 Resilient Cities Network.

RAPs focused on weather extreme conditions will be important outputs of the RESCCUE project as they ensure the reduction in loss of life and damages to assets and guarantee the continuity of urban processes and city services in case of catastrophic events and severe pressures related to climate change scenarios. By developing three different RAPs in the three validation cities, the consortium will obtain a clear view of how the innovative models and tools are able to contribute to a key need for any other city interested in improving its urban resilience levels.

2.2. RESCCUE Goals

As presented in Section 2.1, the main goal of RESCCUE is to help cities around the world to become more resilient. To achieve this overall goal, a set of specific objectives are pursued, including:

1. Compilation, generation, and analysis of different local climate simulations to set up future climate-related scenarios in a coherent way and suitable for users' needs.
2. Improve the understanding of the effects of selected climatic drivers on the urban water cycle in each research site and identify vulnerabilities of each urban service that will lead to increased social security.
3. Assess the direct impacts of these drivers on all the urban services and the cascade collateral impacts on the ones connected to them for current situation and future climate change scenarios. The impacts will be assessed in terms of hazard and risk for each analyzed urban service for the whole set of selected scenarios at each research site.
4. Validate and further develop a specific existing tool and methodology (HAZUR®) to assess urban resilience with respect to different climatic pressures, based on the interaction among different urban services. Define key performance indicators (KPI) to be applied into the subsequent simulations to indicate alert levels. In addition, the improvements related to the operational performance of urban systems will be evaluated, as the urban resilience framework generated will be designed to be adapted to the operational platforms currently in use by urban operators.
5. Explore and assess the economic and societal impacts of multiple feasible mitigation and adaptation measures and technologies to reduce climate change effects on the urban services and their collateral impacts. Based on the impacts evaluated on key urban services and on the needs of end users enrolled in the RESCCUE project, an inventory of the most appropriate mitigation and adaptation options with special focus on nature-based solutions will be established. The result will constitute a portfolio of validated and prioritized improving resilience strategies based on multi-criteria analysis, integrating technological and non-technological alternatives, to better cope with challenges raised by climate change.
6. Elaborate a RAP for each of the case study cities, considering the inputs of all local partners and stakeholders of each site and led by the three involved local resilience offices. The civil protection and emergency sectorial plans will be analyzed to improve coordination during shocks and stresses, as these plans can benefit from RAPs inputs and vice versa.

7. Build a shared awareness and perception of challenges and opportunities, to guide actions and future collaborative approaches, by engaging leading universities and research centers, local governments, large companies, SMEs, non-governmental organizations and citizens from the three research sites.
8. Deliver an Exploitation and Business Plan including a detailed market assessment of the RESCCUE outputs to undertake a proper market deploy of the set of models and tools created once the project is completed.
9. Dissemination and networking, in particular towards the potential users and customers. Agreements on intellectual property (IP) and exploitation rights will be signed within the consortium and, when appropriate, with external potential end users.

2.3. RESCCUE Methodology

The RESCCUE project is being implemented through a set of eight WPs (Work Packages) described below (WP1 to WP6 is where the technical work is focused, whereas WP7 deals with communication and exploitation and WP8 is related to project management). Figure 1 depicts the project structure adopted by RESCCUE specifying the relations among WPs and the main outputs.

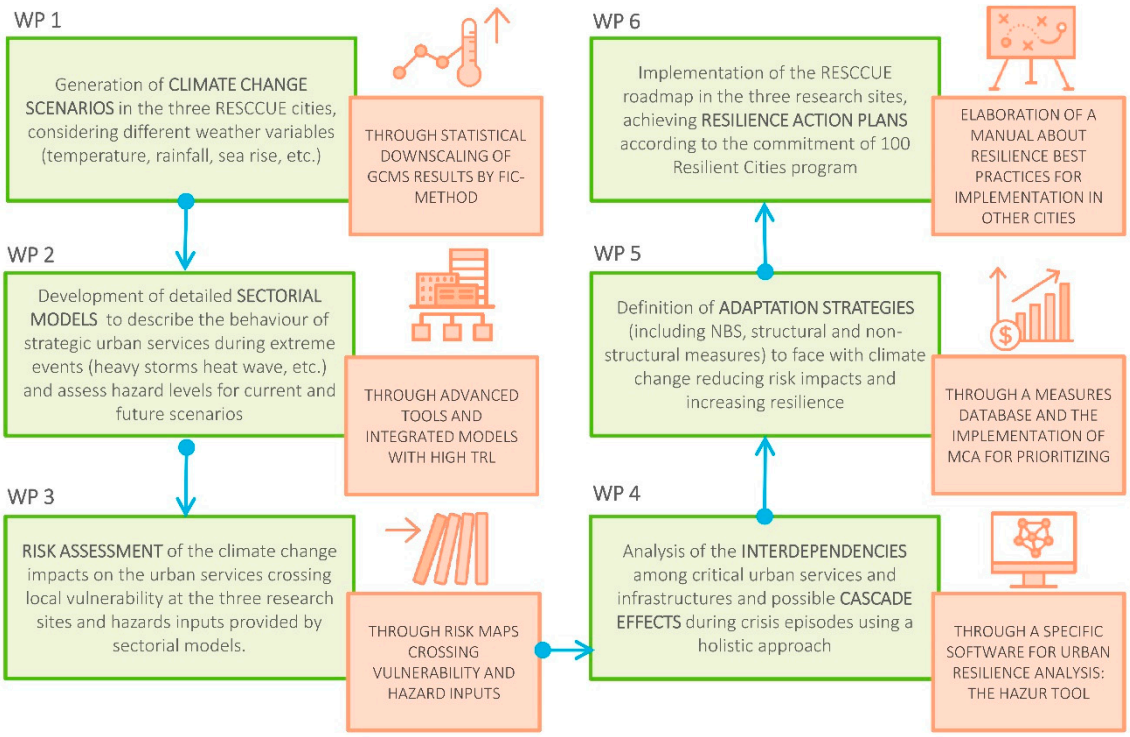

Figure 1. RESCCUE Project structure and technical details.

In WP1, potential future climate scenarios of temperature, sea level and mean and extreme precipitation are being generated at local scale to estimate the probability of the main hazards (such as heat waves, droughts, extreme rainfalls, and sea level rise) in the three research sites and identifying the most critical situations [11,12]. The projections of these variables will have the spatial and temporal resolution required by the sectorial models used in WP2 to simulate the effects of climate change on the strategic urban services of each city.

WP2 starts from the outputs of WP1 and is based on a thorough characterization of the urban systems and their relations with climate variables. Here, potential hazards related to several urban services will be identified and assessed for current and future scenarios. Hazard maps will be elaborated to understand and evaluate the potential effects of the projected pressures on the strategic

urban services and consequently on the city resilience. These analyses will be carried out using a wide range of models, sometimes integrating some of them, as required by the several urban services considered.

WP3 is focused on vulnerability and risk assessment, so it needs the output (hazards) provided by WP2. In WP3, all criticalities and vulnerabilities (for current and future scenarios) of each urban service will be identified and crossed to sectorial hazards to obtain specific risk maps.

WP2 and WP3 will achieve sectorial results in terms of hazard, vulnerability and risk through detailed models simulating the behavior of specific services under pre-determined pressures and drivers concerning current and future scenarios.

WP4 is providing an integral view estimating the cascade effects that imply collateral impacts on several strategic urban services generated by the failures of critical infrastructures. The resilience framework has been defined and urban resilience for current and future scenarios have been assessed for each research site using HAZUR®. HAZUR® is a web-based tool supported by a methodology that currently provides an assessment of the urban services and critical infrastructures status under certain pressures. Through the RESCCUE project, it will be updated to become a crisis management and planning tool. The innovation of this tool lies in the improvement of city resilience through a cross-functional operation and management of its urban services and critical infrastructures. It also accounts for interdependencies and cascade effects among urban services and infrastructures, so it constitutes the perfect starting point to develop a further sophisticated and complete set of models and tools that will allow a better analysis, management and planning of the city.

In WP5, mitigation and adaptation strategies will be defined and promoted to improve urban resilience and to cope with climate change effects. They will be defined with a multisectorial approach, avoiding risk transfer, and increasing urban resilience as a whole. Methodologies to assess their effectiveness and ease their selection (such as Cost Benefit Analysis or multi-criteria analysis) will also be used.

WP6 will validate the models and tools developed from RESCCUE, enabling the implementation of a roadmap for resilience building to climate change-related events in the Barcelona, Lisbon, and Bristol cases, having the urban water cycle in the core. Drivers and opportunities, context, existing practices, and knowledge of each city will be considered to validate the results obtained from previous WPs and to provide feedback to them after it. During WP6, RESCCUE will organize workshops with local partners and stakeholders to provide valuable input and cooperation in the project. Such meetings will take place at each of the three research sites. Resilience Action Plans focused on climate change impacts will be created in this WP by the three involved local resilience offices, considering the inputs of all local partners and stakeholders. A manual of best practices will also be prepared in this WP, to ensure replicability of the RESCCUE results, reaching far beyond the three studied cases.

As explained, the use of detailed models and software tools is essential to analyze the behavior and the response of strategic services and critical infrastructures with respect to specific pressures and drivers related to climate change. Moreover, the outputs of these sectorial models will be used to assess hazard, vulnerability, and risk levels for current and future scenarios where a large set of measures and strategies will be simulated and evaluated in terms of impacts reduction.

Once the detailed knowledge of each urban service has been acquired through available data, past experiences, and simulation results, then the interdependencies between them and the cascade effects due to failures or extreme climate events can be studied. Within RESCCUE, this is done with two different approaches characterized by a different level of detail (Figure 2):

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), using the outputs of one as inputs of the other, being able to simulate cascading effects in a detailed but simple way. In this case, adaptation strategies and measures will

be proposed and prioritized based on 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 analyzed. 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

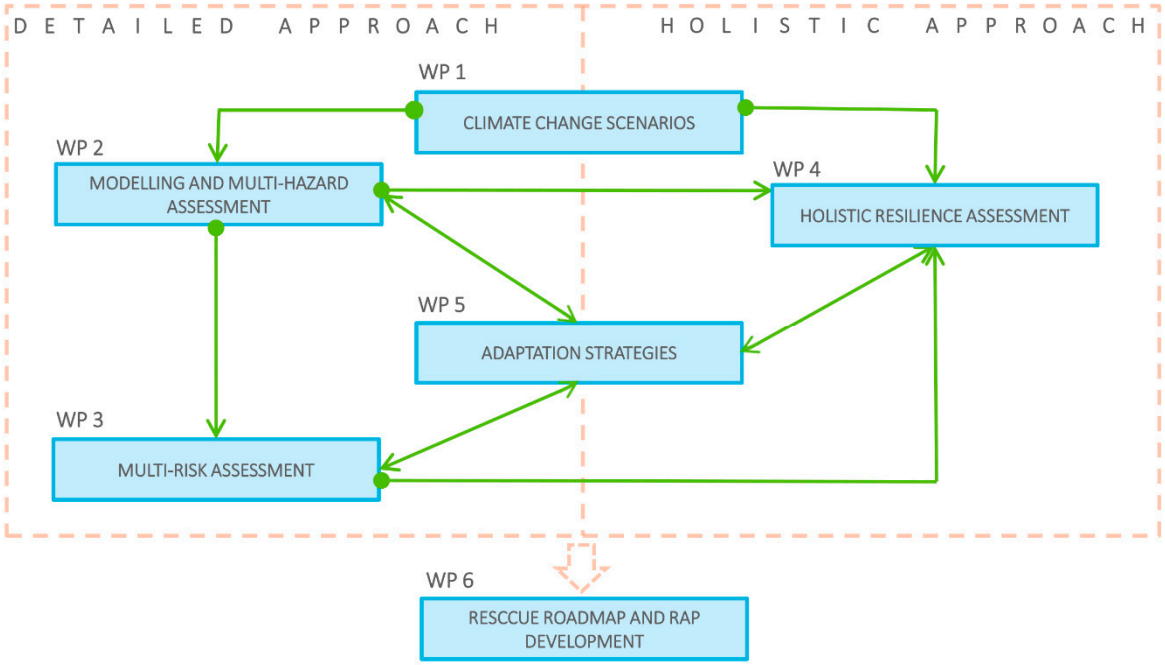

Figure 2. Summary of RESCCUE framework.

With the detailed approach, the detailed analysis of hazard and risk produced by complex interactions and cascade effects involving different urban sectors is done. Then, as not all sectorial models are studied in detail and coupled with others, the whole spectrum of interdependencies and cascading effects is then covered by the holistic approach with a minor level of detail.

The two approaches presented before, coexist in the several different work packages studied in the RESCCUE project. Whereas some tasks are only part of the detailed approach, some others only focus on the holistic one, while there are a few that belong to both, linking the two and allowing to combine them.

The combination of both approaches allows to understand the functioning of the city as a whole, while focusing in some very detailed impacts that are crucial to understand how the several city services affect each other.

By having this detailed—holistic approach, the RESCCUE project will be able to deliver a very useful resilience roadmap for the cities in the form of a RAP, where the strategic lines in which the city must focus are also fed with concrete measures that will be applied to solve specific problems.

2.4. RESCCUE Research Sites

RESCCUE is built around three research sites (Barcelona, Bristol, and Lisbon) that represent different challenges in terms of urban resilience building. These research sites have been selected due to their strong involvement with the urban resilience as demonstrated by their selection and participation in the 100 Resilient Cities program founded by the Rockefeller Foundation. This award has allowed the creation of specific resilience offices with the aim of creating strong synergies among

city actors to ensure reduction in loss of life and damage to assets and the continuity of urban services and critical infrastructures performance during emergencies. The three research sites had already identified water-related risks as crucial in their hazard analysis, which is a common feature that the three of them share (Figure 3).

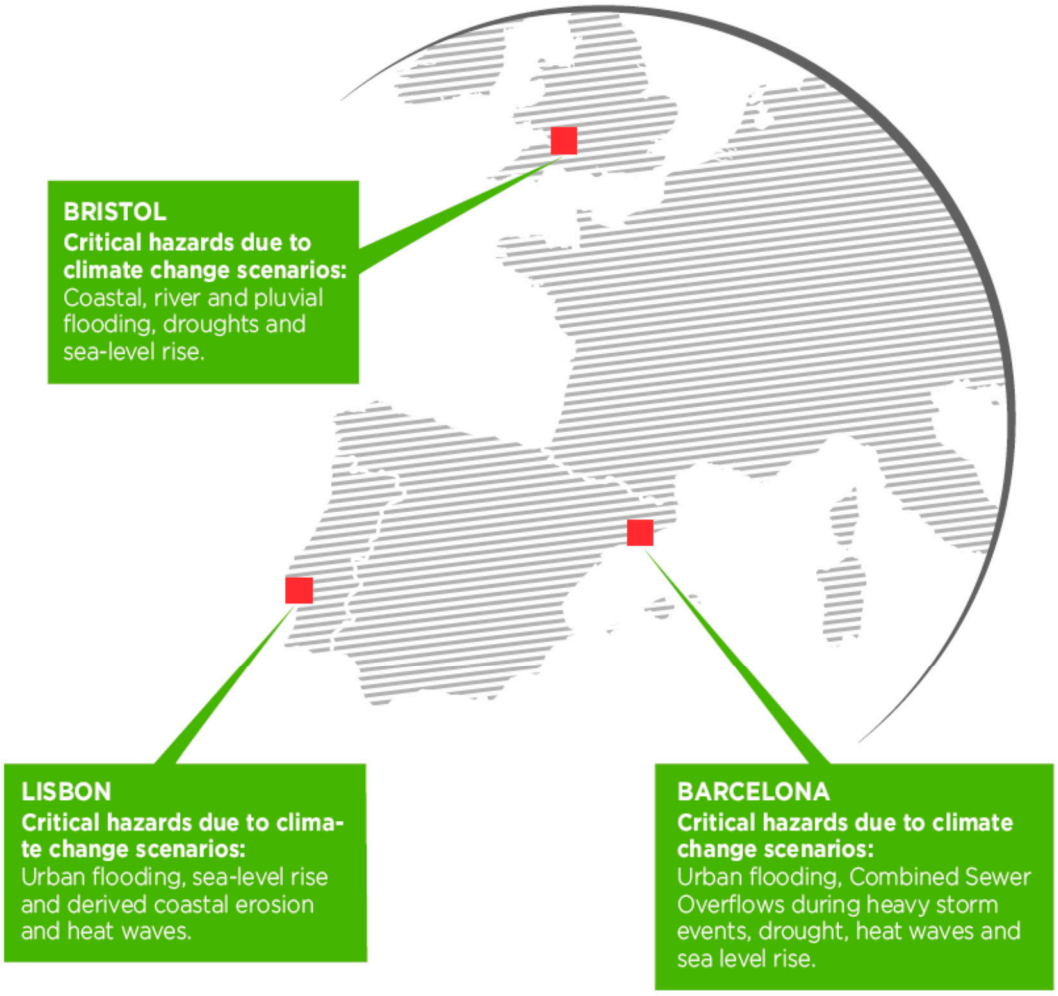

Figure 3. RESCCUE research sites considered hazards.

Moreover, they have been selected based on other relevant criteria such as previous R&D knowledge of the local involved partners, end users in need for solutions and SMEs with high potential for innovation and replication. In addition, the three sites cover a representative range of climate conditions with expected strong impacts from climate change. For each research site, the RESCCUE consortium is represented by relevant partners including leading research centers or universities, local city councils, strategic local service managers and SMEs. On the other hand, several local authorities are linked to RESCCUE consortium as stakeholders. Finally, UN-Habitat guarantees the dissemination of the project results through their access to major resilience and risk reduction events and their leading position in urban resilience topics at international level.

In particular, Barcelona is involved in the City Resilience Profiling Program (CRPP) promoted by UN-Habitat to implement the UN Plan of Action on Disaster Risk Reduction for Resilience. In addition, the headquarters of UN-Habitat's CRPP are in Barcelona itself, easing their participation in the project and enhancing the commitment of the city to urban resilience.

The three selected cities have some common aspects in terms of climate change-related risks, such as the several types of flood hazards they must cope with. In the case of heat waves, both Barcelona

and Lisbon currently suffer from them, but this is not the case of Bristol which is located further north and is influenced by the Atlantic Ocean.

In terms of city structure and functioning, they are fairly diverse. While Barcelona has an extremely high population density, Lisbon and Bristol have lower figures that also imply less concentrated urban networks. City size is also a differentiating characteristic: Barcelona and Lisbon are large cities in terms of population, especially if we account for the fluctuating population they welcome all year long; on the other hand, Bristol is a medium size city with minor seasonal variation in population.

Given their differences in size and the fact that they are in different countries, the governance structure in the three cities is diverse. These conditions will allow RESCCUE to have a wide enough validation platform to demonstrate that results have been proven in a broad operational environment.

3. Expected Results

Through a multisectorial approach and a new philosophy promoted by the local resilience offices, RESCCUE wants to remove traditional obstacles related to sectorial analysis and set up incentives to public-private cooperation.

As presented in the previous sections, one of the main results will be the elaboration of Resilience Action Plans in the three research sites. However, in reaching that point, a lot of intermediate results will be achieved, both in terms of models and tools developed, as well as methodologies, assessments, datasets, and other kinds of outputs. To exploit all the RESCCUE results, making sure that they can be used in further research activities and ensuring the replicability of RESCCUE, a Dissemination and Exploitation Plan will be generated (in the framework of WP7, which precisely deals with dissemination and exploitation of the project). This plan, together with the rest of RESCCUE deliverables, will be made available through the Project website: www.resccue.eu (which is not only a project website, but also aims to become a resilience awareness portal, with a dynamic blog regularly updated by all RESCCUE partners).

Although a lot of different results will be produced along the four years of the project, a short list of the most important ones is shown below, along with their associated delivery date (the starting date of the project was May 2016):

- Identification of models of the urban services in the three cities (M06)
- Definition of the framework for impact assessment (M12)
- Generation of climate simulations for the pilot cases (M18)
- Definition of resilience strategies framework and database (M18)
- Resilience Assessment with HAZUR® tool in the three cities (M18)
- Hazard assessment for extreme events (M24)
- Generation of extreme weather events (M24)
- Integration of new functionalities in HAZUR® tool (M30)
- Development of methodologies for resilience strategies (M36)
- Assessment of the impacts of climate change on urban services (M36)
- Assessment of impacts considering cascading effects (M36)
- Definition of a Resilience Action Plan for each research site (M40)
- Enhanced communication system for stakeholder participation (M48)
- Manual of best practices to prepare a RAP in any city (M48)
- Resilience Management with HAZUR® in the three cities (M48)

All these results will be summarized in a report and therefore, they will be made available publicly on the RESCCUE website. The data generated will also be made available for re-use and replicability of the research results in online open data repositories as requested by the open data regulations of the European Commission. On the other hand, some of the models and tools generated and updated will also be exploited via commercialization and licensing by the owners. Finally, several

publications in scientific journals are also expected and as of now, two research papers have already been published [13,14].

Overall, RESCCUE will generate a wide range of outputs that will bring benefits to cities around the world, city councils and public service operators, the European Commission and the RESCCUE Consortium. In all cases, the final beneficiaries of the innovations generated will be the citizens, which will benefit from the safety increase of their cities, as well as a general improvement on the quality of life on their urban living conditions.

In summary, Figure 4 presents the key final results of RESCCUE (associated with each WP), which will come at a different time, varying from the month 24 (May 2018) to the 48 (May 2020).

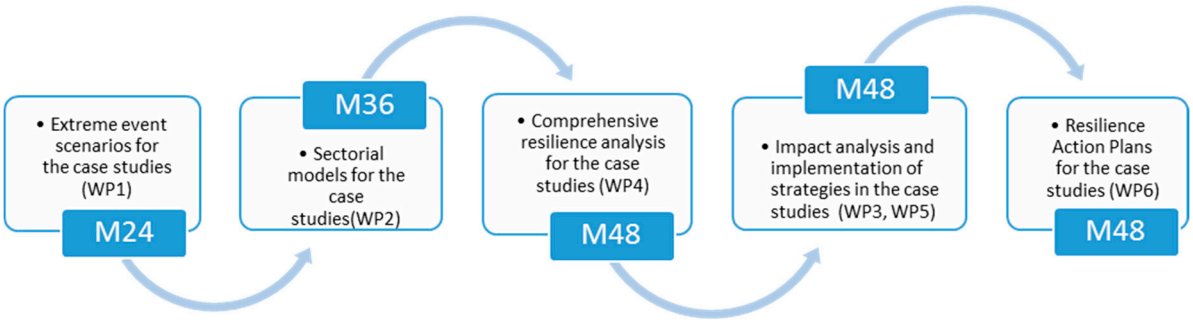

Figure 4. RESCCUE key results and their expected delivery date.

4. Conclusions

RESCCUE will have a significant impact on the urban resilience sector in Europe, because it will deliver tools to enable city resilience assessment, planning and management and it will incorporate new knowledge of the urban systems performance under climate change conditions that is currently not integrated in this type of tools.

The understanding of the complex system represented by a city is a major challenge for assessing the impact of planned measures, making pertinent and optimal choices, and reporting to stakeholders. Moreover, impacts of climate change can cause critical disruptions to urban services in a more frequent basis.

As most of world population will end up living in cities, it is critical and highly urgent to have tools available to assess, plan and monitor urban resilience in an integral way. This urgency, justified by the already proven climate change effects, will favor the rapid deployment of RESCCUE's tools.

RESCCUE will contribute with a set of innovative tools for urban resilience assessment, planning and management. These tools will help cities with their climate change adaptation strategies while they also improve their current capacity to cope with emergencies.

Cities around the world are very diverse in terms of their functioning and the exposed hazards, the RESCCUE project will try to make sure that the results obtained here can be easily deployed to any other city around the world. To achieve this, counting with the support of UN-Habitat is a key element to ensure the replicability of results.

Author Contributions: P.M. is the Coordinator of the RESCCUE Project; M.V. is the Project manager of the whole project; R.M. is the leader of WP1; B.R. is the leader of WP2; S.D. is the leader of WP3; I.F. is the leader of WP4; S.V. is the leader of WP5, M.A.C. is the leader of WP6; A.B. is the leader of WP7; and M.M. is the leader of WP8.

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