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RAF Resilience Assessment Framework—A Tool to Support Cities' Action Planning

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Abstract: Urban areas are dynamic, facing evolving hazards, having interacting strategic services and assets. Their management involves multiple stakeholders bringing additional complexity. Potential impacts of climate dynamics may aggravate current conditions and the appearance of new hazards. These challenges require an integrated and forward-looking approach to resilient and sustainable urban development, being essential to identify the real needs for its achievement. Several frameworks for assessing resilience have been developed in different fields. However, considering the focus on climate change and urban services, specific needs were identified, particularly in assessing strategic urban sectors and their interactions with others and with the wider urban system. A resilience assessment framework was developed directing and facilitating an objective-driven resilience diagnosis of urban cities and services. This supports the decision on selection of resilience measures and the development of strategies to enhance resilience, outlining a path to co-build resilience action plans, and to track resilience progress in the city or service over time. This paper presents the framework and the main results of its application to three cities having diverse contexts. It was demonstrated that the framework highlights where cities and urban services stand, regarding resilience to climate change, and identifies the most critical aspects to improve, including expected future impacts.

Keywords: resilience assessment; urban resilience; climate change; urban services; cities

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1. Introduction

Urban areas are complex, vulnerable and continuously evolving systems. In these dynamic areas, the existence of interacting strategic services and of interdependent services and assets, as well as the involvement of a multiplicity of stakeholders, adds complexity to their management. Besides, the significant impacts of climate dynamics (such as intense precipitation events, tidal effects, droughts or heat waves) in the urban strategic services, people, natural environment and economy, as well as the aggravation of current conditions and the emergence of new hazards, also need to be considered in their management [1,2].

As referred to in [3], following the World Economic Forum 2014, by 2050, exposure of city dwellers to various hazards, including earthquakes, tsunamis, urban floods, cyclones and storm surges, is expected to double. These challenges require an integrated and forward-looking approach to resilient and sustainable urban development, incorporating the interdependencies between systems as well as including stakeholders and citizens perceptions and needs. In order to achieve this, several long-term agendas have been adopted as parts of the United Nations Agenda 2030 for Sustainable Development, such as the Sendai Framework for Disaster Risk Reduction 2015–2030, the Sustainable Development Goals, the New Urban Agenda and the Paris Agreement [3]. A relevant consideration in all of these agendas is the incorporation of assessment steps for tracking their implementation [4].

The resilience concept has evolved over time and among disciplines [5,6]. Herein, urban resilience refers to the ability of human settlements to withstand, recover quickly and adapt from any plausible hazards. Resilience to disruptive events not only refers to reducing risks and damage from disasters, but also the ability to quickly bounce back to a stable state. Besides addressing disaster risk reduction, resilience includes changes in circumstances [7–10].

In order to identify the real needs for enhancing urban resilience, as well as the efficiency and effectiveness of planned or implemented measures, a resilience assessment is essential. Therefore, assessing the current and expected future status of resilience is a basis for cities to know where they are, helping to identify strengths and weaknesses, thus supporting the decision on strategies, actions and measures to be taken, planning for the long-, medium- and short-terms and assessing the progress.

Since the cities are dynamic systems with evolving hazards, it is essential to regularly carry out the assessment of their resilience, considering the principle of continuous improvement [11], and to have tools to support this. Several tools and frameworks for assessing resilience have been developed in different fields of study by a wide variety of stakeholders, such as those created by Local Governments for Sustainability (ICLEI) 2010, UN-Habitat City Resilience Profiling Tool (UN-Habitat CRPT) 2013, Rockefeller and Arup 2014, World Bank 2015, United Nations Office for Disaster Risk Reduction (UNDRR, former UNISDR) 2017, U.S. Environmental Protection Agency (EPA) 2017, among others [5,7–9,12–16]. Within the scope of the current work, i.e., climate change with a focus on water, relevant resilience assessment frameworks are presented in Table 1. It synthetizes the themes, urban sectors and metrics considered in each framework [5,7,13,16,17].

Table 1. Synthesis of resilience assessment frameworks for climate change.

Framework	Themes Addressed						Sectors Addressed							No. of Metrics	Reference
	Governance	Social	Spatial	Built environment	Economy	Natural Environment	Water	Wastewater	Stormwater	Waste	Energy	Mobility	Other(s) *		
EPA conceptual framework	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	163	[15]
City Resilience Framework	✓	✓	✓										✓	156	[13]
UNDRR Disaster Resilience Scorecard for cities	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	47 preliminaries 117 detailed	[8,9]
City Resilience Index to Sea Level Rise	✓	✓		✓	✓	✓	✓						✓	13	[18]
Climate Disaster Resilience Index	✓	✓		✓	✓	✓						✓	✓	120	[19]
Climate Disaster Resilience Index	✓	✓		✓	✓	✓						✓	✓	82	[20]
Climate Resilience Screening Index	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	117	[16]
Flood Resilience Index	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	91	[21]
Resilience Factor Index	✓	✓		✓	✓								✓	17	[22]
Community disaster resilience	✓	✓		✓	✓	✓							✓	26	[23]

Table 1. *Cont.*

Framework	Themes Addressed						Sectors Addressed							No. of Metrics	Reference
	Governance	Social	Spatial	Built environment	Economy	Natural Environment	Water	Wastewater	Stormwater	Waste	Energy	Mobility	Other(s) *		
NIST (National Institute of Standards and Technology) Community Resilience Assess. Methodology	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓	-	[24]
UKWIR (UK Water Industry Research)						✓	✓	✓	✓					73	[25]
UN-Habitat CRPT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	148	[7]

* e.g., Telecommunications, healthcare, education, population.

Taking into account the mentioned scope, the need of a framework (Table 1) that is freely available to be usable by cities and urban services managers was identified, allowing, on the one hand, a structured and objective-driven assessment of their city's resilience considering the integration of all themes and sectors simultaneously and, on the other hand, an assessment of resilience of a single sector considering its interdependencies with other sectors and its contribution to the city resilience.

Grounded in the analysis of these existing frameworks, and in order to bridge the additional gaps and needs identified, particularly in the assessment of strategic urban sectors and their interactions with both other sectors and in the wider urban system, the Resilience Assessment Framework (RAF) was developed—a resilience assessment framework with focus on climate change and the water cycle, herein described.

2. Materials and Methods

2.1. RAF—Resilience Assessment Framework Aims, Assumptions and Development Approach

Considering the challenges of urban areas related to the potential effects of climate dynamics, enhancing urban resilience requires: (i) identification of the real needs, (ii) sustainable action planning and (iii) assessing progress. In order to support the mentioned requirements, bridging the gaps and the abovementioned needs identified, a Resilience Assessment Framework (RAF) was developed with the main purpose of contributing to the referred requirements, namely:

(i) Directing and facilitating a structured resilience diagnosis of the cities and of the strategic urban sectors, following an objective-driven approach [11] with defined assessment criteria and identifying data gaps, opportunities, threats, strengths and weaknesses, highlighting the areas for improvement.
(ii) Outlining a path for the development of cities' resilience action plans by supporting decision-making in the selection of resilience measures and the development of strategies to enhance resilience.
(iii) Monitoring the resilience progress of a city or service over time, by applying it periodically, and facilitating communication among stakeholders.

The RAF described herein considers the following assumptions:

- The scope is urban resilience to climate change (CC), with a focus on the water cycle, meaning that other diverse resilience drivers such as earthquakes, economic crises and cyberattacks, are not taken into account.
- The emphasis is on the city, services and infrastructure resilience, meaning that resilience aspects such as social and political are not developed for diagnosis, but they are incorporated whenever significant for city, services' and infrastructures' resilience.

- The services within the RAF scope are those comprised in the urban water cycle, water supply, wastewater and storm water and those having interconnections and interdependencies, closely related with the water services: waste management, electrical energy supply and mobility.
- The external context of the city and services is considered by a standard characterisation profile of the city and of the services, since it is fundamental to identify the main threats and to support the assessment, particularly the interpretation of results.
- The city and services multi-scale, multi-sectoral, multi-hazards and interdependencies are addressed, meaning that the RAF incorporates: different scales—city, services and infrastructure, the diverse sectors presented above, assessment of several hazards and of aspects related to interdependencies between different services and infrastructures.
- The continuous improvement principle [11] is followed and, since cities are dynamic, it addresses the progress of the strategies' implementation and considers their effect, before, during and after an event and changes in circumstances.
- The long-, medium- and short-terms are incorporated considering three different and aligned assessment levels for the city, services and infrastructures (strategic—overlooking a long-term planning horizon and requiring the involvement of the entire organisation, addressing the overall city and considering its vision; tactical—overlooking a medium-term planning horizon and addressing departmental or sectoral activities in the city, services and infrastructure; and operational—referring to short-term horizon, addresses the actions to be taken in the effective implementation of measures in the city, services and infrastructure) while, as an integrated assessment, addresses the two first.
- A flexible structure is used, based on assessment metrics, allowing it to be expanded to other resilience drivers, dimensions or services.

The development and implementation of the assessment process, in collaboration with different stakeholders, promotes their empowerment and enhance their role in the decision-making process [26], as well as in the implementation of improvement solutions. To consider this, the RAF development was carried out in a stepwise process (Figure 1), comprising the analysis of existing assessment frameworks and related recommendations, and the definition of a preliminary proposal, which was validated to produce the final version.

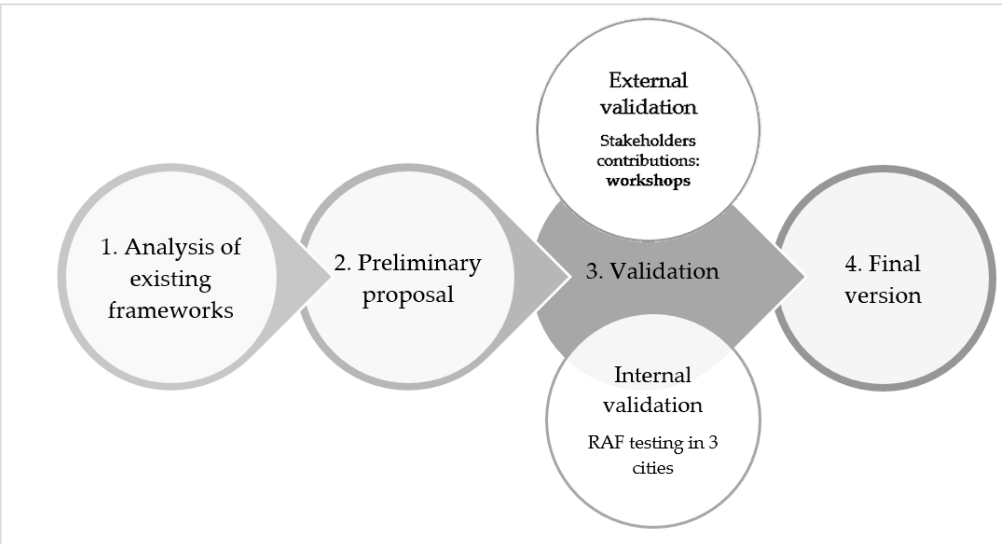

Figure 1. Resilience Assessment Framework (RAF) development process flow chart.

The validation process included an external and an internal validation [26]. The external validation involved different stakeholders, representatives of research organisations, city departments and urban service utilities, allowing for incorporating their concerns as well as their own context and reality through collaborative workshops. Three workshops were implemented in each city, Barcelona (Spain), Lisbon (Portugal) and Bristol (UK), to obtain the stakeholders' opinion on the RAF relevance, structure and applicability, as well as their concerns, own context and reality. Overall, 24 to 38 stakeholders attended each of the sessions, from 13 to 24 different organisations, answering individually and by sector to several surveys.

To ensure coherence, feasibility and effectiveness of the approach, the internal validation was carried out in the abovementioned cities, having different characteristics and contexts, which applied this framework involving the respective stakeholders. Each city and respective services provided their own data and answers to all applicable metrics. From the external and internal validation analysis, it was possible to identify the RAF components that benefited from additional improvements and those that less fitted the cities' available information, thus supporting the development of the final framework herein presented. It is important to take into account that cities are multi-dimension entities and, therefore, urban resilience needs to consider multidisciplinary insights. Additionally, resilience of a city is determined by diverse interacting systems and their relationships. For this reason, resilience also depends on the overall performance, interactions and capacity of its systems in their everyday operation, not solely on its ability to cope with specific natural hazards or to adapt targeted areas to the impacts of climate change [27]. Thus, it is essential to address interdependencies and cascading effects [28]. Another relevant aspect is that it needs to include both sudden crises as well as interacting long-term stressors, address multiple hazards, characterise the specific geographic extent, consider physical dimensions, involve community members and be adaptable and scalable to different communities and changing circumstances [24]. These requirements were considered in the RAF development.

2.2. RAF—Resilience Assessment Framework Description

RAF sought alignment with international frameworks for resilience assessment, particularly with UNDRR Disaster Resilience Scorecard, both preliminary and detailed levels [6,7], and UN-Habitat, and made significant developments with regard to its scope and focus on urban services. The RAF considers the UN-Habitat resilience dimensions [29]: organisational (integrates top-down governance relations and urban population involvement, at the city level), spatial (referring to urban space and environment), functional (resilience of strategic services) and physical (resilience of services infrastructure). Time dimension is implicitly integrated as part of the analysis. The RAF (Table 2) has a hierarchical tree structure (Figure 2) meaning that, for each dimension, resilience objectives are defined, representing the ambitions to be achieved in the medium–long term by the city and services. For those dimensions related to the urban services, they firstly unfold into sub-dimensions, where each sub-dimension represents one service to be assessed. Each objective is described by a set of criteria that translate the different points of view associated with it. Each criterion assembles the respective assessment metrics, through which it is possible to classify the resilience development level by comparison with reference values. Metrics are then defined consisting in questions, parameters or functions used to assess the criteria. Some of the RAF metrics correspond to or were adapted from existing frameworks, mainly from UNDRR framework (former UNISDR)—found to be highly relevant for the scope of the RAF, and others were newly developed. In Appendix A, the complete structure is presented. As an example, Table 3 illustrates the metrics definition to assess, within the spatial dimension, the objective of spatial risk management from the perspective given by the criterion impacts of climate-related events, showing the hierarchical tree structure mentioned above.

Table 2. Overview of the RAF dimensions.

ORGANISATIONAL		
OBJECTIVE Criterion	No. total metrics	No. essential metrics
COLLECTIVE ENGAGEMENT AND AWARENESS		
Citizens and communities' engagement	5	3
Citizens and communities' awareness and training	5	3
LEADERSHIP AND MANAGEMENT		
Government decision-making and finance	4	3
Coordination and communication with stakeholders	4	2
Resilience engaged city	19	13
CITY PREPAREDNESS		
City preparedness for disaster response	13	8
City preparedness for CC	7	6
City preparedness for recovery and build back	7	5
Availability and access to basic services	10	7
TOTAL	74	50

SPATIAL		
OBJECTIVE Criterion	No. total metrics	No. essential metrics
SPATIAL RISK MANAGEMENT		
General hazard and exposure mapping	5	5
Hazard and exposure for CC	3	3
Resilient urban development	7	4
Impacts of climate-related event	2	2
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS		
Protective infrastructures and ecosystems services	9	6
Dependence and autonomy regarding other services considering CC	3	2
TOTAL	29	22

FUNCTIONAL		
OBJECTIVE Criterion	No. total metrics	No. essential metrics
SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning	5	5
Resilience engaged service	5–6	4–5
Risk management	7–12	2–7
Reliable service	6–11	1–5
Flexible service	4–6	1–4
AUTONOMOUS SERVICE		
Service importance to the city	2	1
Service inter-dependency with other services considering CC	2	0
SERVICE PREPAREDNESS		
Service preparedness for disaster response	0–4	0–4
Service preparedness for CC	6–8	4
Service preparedness for recovery and build back	0–15	0–8
TOTAL	37–71	18–43

PHYSICAL		
OBJECTIVE Criterion	No. total metrics	No. essential metrics
SAFE INFRASTRUCTURE		
Infrastructure assets criticality and protection	5	5
Infrastructure assets robustness	10–14	4–6
AUTONOMOUS AND FLEXIBLE INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services	3–4	3
Infrastructure assets autonomy	1–6	0–4
Infrastructure assets redundancy	1–3	0–3
INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience	3–4	2–3
Infrastructure assets exposure to CC	3	0–3
Preparedness for CC	2	1
Preparedness for recovery and build back	7–9	2–4
TOTAL	35–50	17–32

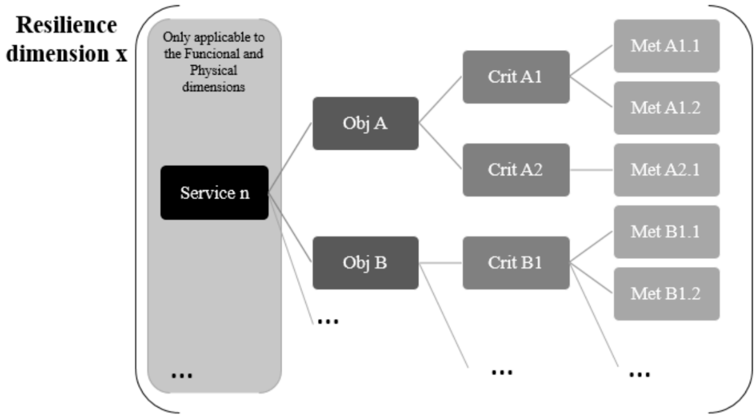

Figure 2. RAF tree structure.

Table 3. Metrics definition—example for spatial dimension, objective spatial risk management, criterion impacts of climate-related event.

DIMENSION: SPATIAL		
OBJECTIVE: SPATIAL RISK MANAGEMENT		
Criterion: Impacts of Climate-Related Event		**Unit**
Metric: S16	*Human loss in the last events*	(-)
Definition	Human impact of the last climate-related event, with similar or harsher climate variables than the most probable scenario	
Dimension Importance	Spatial	
Metric type	Essential	
	Open value	
Please answer with an estimated figure [inhab.], disaggregating according to (a) number of casualties, (b) missing persons and (c) people affected—including severe injuries and displaced. This metric allows to answer with a value.		*Develop. Level*
Development level: assessment rule		*3 if a, b and c = 0* *2 if a and b = 0 and c ≤ 50* *1 if a = 0, b ≤ 5 and c ≤ 50* *0 if any other answer*
- *(a) number of casualties* - *(b) missing persons* - *(c) people affected—including severe injuries and displaced*		
Metric: S17	*Damages in urban footprint in the last events*	(%)
Definition	Impact on urban footprint of the last climate-related event, with similar or harsher climate variables than the most probable scenario	
Dimension Importance	Spatial	
Metric type	Essential	
	Single choice	
Consider urban footprint as a spatial extent of urbanised areas on a regional scale.		
Development level: assessment rule		*Develop. level*
- *0%*		*3*
- *Less or equal to 0.5%*		*2*
- *Between 0.5% and 2.5%*		*1*
- *More or equal to 2.5%*		*0*

The framework considers past, existing and future conditions in the assessment. To incorporate the uncertainties associated to expected variations in climate-related variables, some metrics are specific to CC assessment scenarios, namely those that address preparedness for CC, and that anticipate the city and services' exposure or vulnerability to future scenarios. Besides, the consideration of reference values allows to generally address uncertainties in the assessment.

A relevance degree is assigned to each metric, namely: essential, corresponding to all metrics with higher relevance, required to integrate the resilience assessment of any city or service, complementary, additional metrics to be considered whenever integration of city or service specific aspects is sought, corresponding to a more detailed resilience assessment and comprehensive, additional metrics recommended whenever a more in-depth assessment is aimed, for a city or service with higher maturity in its resilience path. Accordingly, depending on the resilience maturity, the city or service aiming to apply the RAF may select a given set of metrics, according to their relevance.

Additionally, every city or urban service needs to operate in its own specific political, economic, geographical, climatic and cultural context. Considering the context information is fundamental in interpreting any assessment. Following this, city and services' characterisation profiles were developed to integrate the RAF framework, regarding its scope and focus. These profiles require information on geographical characteristics, climate, population, economy and governance, built environment and infrastructures, for the city. Regarding each service, it considers information on context characterisation, climate and infrastructure assets.

2.3. Research Sites

2.3.1. General

In order to test and validate the RAF to assess the cities' resilience to climate change with a focus on the water cycle, it was applied to Bristol (UK), Barcelona (Spain) and Lisbon (Portugal) by the respective cities and strategic services managers. These three cities represent diverse context characteristics as well as different climate change-related concerns. The application was undertaken using the RAF App, a web-based application tool reproducing the RAF structure that allows selection of applicable dimensions and services to assess and allows private submission of answers to the metrics. The results may be visualised graphically (Figures 3–5) and reports are also provided [30].

2.3.2. Bristol

Located in the south-west England, predominantly on a limestone area, Bristol is one of the most densely populated parts of the UK and, after London, the second largest city in the southern region. Most of the urban extent of Bristol is based around the watercourses and river network, with two major rivers flowing through the city (Avon and Frome rivers), resulting in a characteristically hilly landscape. It is one of the warmest cities in the UK and there is a relatively even distribution of rainfall throughout the year, although the autumn and winter seasons tend to be the wettest. Within this context, Bristol has been investing in plans to create and improve resilient systems to tackle its various urban challenges. Based on the analyses conducted by local and international actors working on resilience, the main urban challenges in Bristol can be profiled firstly in terms of natural and environmental hazards and secondly with regards to broader socio-economic issues. Bristol has suffered from significant flooding in the past, with the floating harbour and low-lying city centre being identified as key areas vulnerable to tidal, fluvial and groundwater flooding. The flood of 1968 was one of the most significant and damaging flooding events in the city, caused by both surface water and fluvial flooding that resulted in high damages and impacts to the city and its inhabitants. The construction of large interceptor tunnels in response to this, to divert exceedance flows higher up in the catchment, reduced fluvial flood risk in the city. In 2012, significant flooding occurred across most of the UK due to some of the highest rainfall events since record collection began. During this time, the most notable single flood event lasted two days, with 30 houses internally flooded and many more suffering flooding of gardens, garages and driveways. In order to better manage flood risks in Bristol area, a 'Local Flood Risk Management Strategy' was produced and released in early 2018. The Strategy sets out the Bristol City Council vision for managing flood risk in the city, together with other organisations that have a role in flood-risk management [29]. Bristol City Council has already developed an intensive work towards resilience, and it is proactively committed to increase Bristol's resilience: from social cohesion to economic stresses and by enhancing resilience to all sources of flooding. The resilience of the city to climate change (CC) can be highly related to its urban services' resilience, their interdependencies and cascade effects. For Bristol, the resilience assessment was undertaken for the flooding hazard related to rainfall and sea level variables, by its importance regarding Bristol resilience to CC.

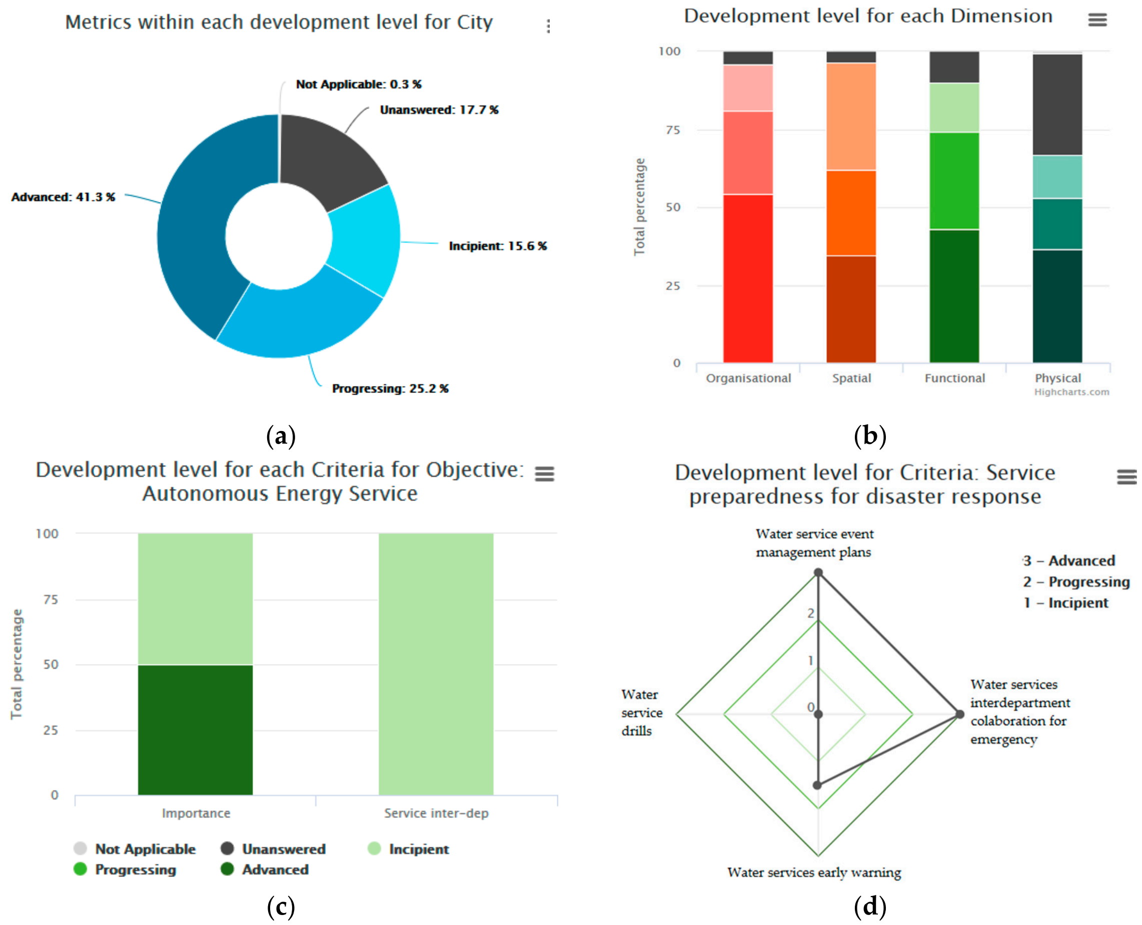

Figure 3. Bristol resilience assessment results for flooding: (**a**) Overall assessment, (**b**) overall assessment per dimension, (**c**) assessment of the objective autonomous electrical energy service, (**d**) assessment of the criterion water service preparedness for disaster response.

2.3.3. Barcelona

Located on the northeast coast of the Iberian Peninsula facing the Mediterranean Sea, Barcelona is the capital city of the autonomous community of Catalonia, Spain. The city is situated on a plain spanning and is bordered by the mountain range of Collserola, the Llobregat river in the southwest and the Besòs river in the north. Barcelona is the second most populous municipality within Spain. However, the population increased slowly but steadily until the 1970's, when the city reached its maximum population, thereafter, it stabilized and even decreased at the beginning of the 21st century, reaching the average population of 1.6 million inhabitants. Barcelona's physical expansion has been limited by the mountains and the sea, resulting in a relatively high population density, among the highest in Europe. Within this context, Barcelona's major vulnerabilities are mainly attributable to the natural and environmental threats faced by the wider Catalonia region. Barcelona's past and recent history has been punctuated with recurrent water crises but also with rainfall events with very strong intensity over short time frames. The most severe and recent disruptive event hitting the urban area was between 2004 and 2008. During that period, four years of scarce precipitation in the Llobregat and Ter rivers' headwaters, coupled with an increased evaporation rate due to high temperatures, culminated in the Spring 2008 water crisis affecting over 5.5 million people in the broader Catalonia. In that context, the Regional Government had to adopt exceptional procedures to minimise water waste, while the City of Barcelona was simultaneously forced to introduce restrictive measures over water use. Since then, several structural measures to ensure water supply have been implemented [29]. In January 2018, the city declared the pre-alert level of the Drought protocol after three consecutive years of low rainfall. The city is affected every year by an average of three intense rainfall events and one extreme flooding event every five years, although these frequencies have been increasing in the last years. Barcelona also has records of one heat wave every four years, a trend that has been increasing notably in the latest years. In 2003, a heatwave that lasted 13 days increased in more than 40% the average mortality. The last heat wave event was in summer 2018, it was 7 days long and caused up to 10 direct deaths. The resilience of the city to climate change can be highly related to its urban services' resilience, their interdependencies and cascade effects. The Barcelona Municipality has already developed an intensive work towards resilience, and it is proactively committed to increase Barcelona's resilience: from social exclusion to economic stresses, flooding, drought and heat waves. For Barcelona, the resilience assessment was carried-out for flooding, combined sewer overflows, drought and heat waves, considering the variables related to rainfall, sea level and temperature.

2.3.4. Lisbon

Located on the northern bank of the Tagus River's estuary, one of the 18 municipalities of the biggest Portuguese metropolitan area, Lisbon is the capital of Portugal and the second largest European port on the Atlantic Ocean. The city has a Mediterranean Climate (Csa), characterised by dry and hot summers and wet and fresh winter periods with a relatively low precipitation rate compared to other Portuguese cities. Lisbon Metropolitan Area, with a population of 2.8 million inhabitants, stretches on both sides of the Tagus River, contributing to 37% of the national economic output. Today, Lisbon is a complex system with more than 1.0 million citizens who live, work, study, circulate and visit the city, Portuguese in the majority, with different ages, cultures, religions, ethnicities, education levels, knowledge and languages. Based on the analyses conducted by both local public stakeholders and international actors working on resilience in Lisbon, one of the urban challenges is related to a combination of contextual environmental, emergency, civil protection and urban planning threats with the contingent impacts of climate change crisis [29]. Since 1950, about 43 relevant events of extreme weather occurred in Lisbon. From these, nine events were related to hot weather, including heat waves, with a maximum temperature of 42 °C recorded in August of 2003, 13 events related to cold weather, including cold waves, with a minimum temperature of −1.2 °C recorded in February 1956, two strong wind and gusts events, with a maximum wind velocity of 108.4 km/h, recorded in January 2014 and 10 rainfall-induced flood events, with a maximum return period of 500 years, recorded in November 1983. The resilience of the city to climate change can be highly related to its urban services' resilience, their interdependencies and cascade effects. Lisbon Municipality has already developed an intensive work towards resilience, and it is proactively committed to increase the resilience of the city: from social exclusion to economic stresses and from seismic shocks to flooding, combined with 17 Sustainable Development Goals' achievement. For Lisbon, the resilience assessment was undertaken for the flooding hazard, related to rainfall and sea level variables.

3. Results

3.1. Bristol

The RAF was applied in Bristol in order to assess the current level of city resilience to flooding. Some results are presented in Figure 3. This could then subsequently identify where the gaps lie and what particular aspects are lacking to help formulate plans to improve or enhance upon the existing status, based on this resilience diagnosis. It went into a great level of detail investigating many aspects of city resilience quite thoroughly. The overall resilience development in the city was deemed as advanced in nearly half of the aspects assessed (Figure 3a). In this same respect, around a quarter were shown as progressing and the remainder incipient, unanswerable or not applicable. Various city services were given consideration including storm water, wastewater, energy, mobility and solid waste management operations.

The analysis highlighted the advancement in organisational areas more so over physical areas (Figure 3b), which were deemed more absent. Infrastructure resilience to climate change is therefore the main concern on reflection of this. In their own respect, the individual services seem resilient to a point, due to a focus on building resilience to historical events in the city and in response to national flood-risk issues. There is, however, susceptibility in the realms of reliance upon inter-related services and a lack of understanding of the cascading impacts and interdependencies between them.

The results from the analysis highlight the coordination between governmental organisations that is not always experienced to the same level externally with all privately run organisations. Engagement with communities is also a dynamic that is not completely to its maximum sufficiency. Availability of service resources is good, since diverse energy sources are used in the city, but the reliance on electricity without alternative provisions is a notable limitation (Figure 3c). Resilience standards to adhere to as well as the position of a Chief Resilience Officer being eliminated make for more areas lacking in Bristol. Learning from past events is a commendable action performed well in Bristol, but the running of emergency scenarios and drills does not appear to be simulated enough to gain its full benefit (Figure 3d). The known threats of a significant proportion from sea level rise and increased rainfall present an extreme level of vulnerability to the city and its inhabitants. There are, however, also opportunities presented, though through the declaration of a climate emergency in Bristol, they require drastic action implemented via a climate strategy. The chance for properly applying climate adaptation measures utilising the knowledge developed of high-risk areas in the city therefore has greater prospect for recognition and the enablement for realisation.

3.2. Barcelona

The RAF enables to highlight where Barcelona and its urban services stand today regarding resilience to climate change, and to identify the most critical aspects to be improved, taking into account both the reference situation and the expected impacts of future climate change scenarios. The diagnosis allowed for understanding those aspects that are being tackled properly from the city and was also to determine gaps and areas of improvement thanks to the great level of detail of the different dimensions that make up the assessment. Some results are presented in Figure 4. The exhaustive analysis led the city to an intense and deep level of self-knowledge about its level of resilience in different ways of approach (Figure 4a). In this sense, the organisational and spatial dimensions yielded good results about the level of response to the metrics considered, reaching a response level of almost 100% (Figure 4b). Regarding the physical and functional dimensions, several services of the city were assessed, namely water, wastewater, storm water, energy, waste management and mobility. The assessment showed those services that are well managed and monitored as waste or water services, but it also highlighted the need of improvement in the energy sector, storm and wastewater and mobility services (Figure 4c,d). For Barcelona, most data gaps can be blamed on the definition of the metrics to be applied and the differences in the way how these metrics are calculated. Most of the time, the indicators did not fit with the ones the city already determines and it would entail a noteworthy effort to address the asked specifications. Without assuming harm, this identification of gaps means an opportunity to improve a new approach to measuring the different aspects of resilience in the city.

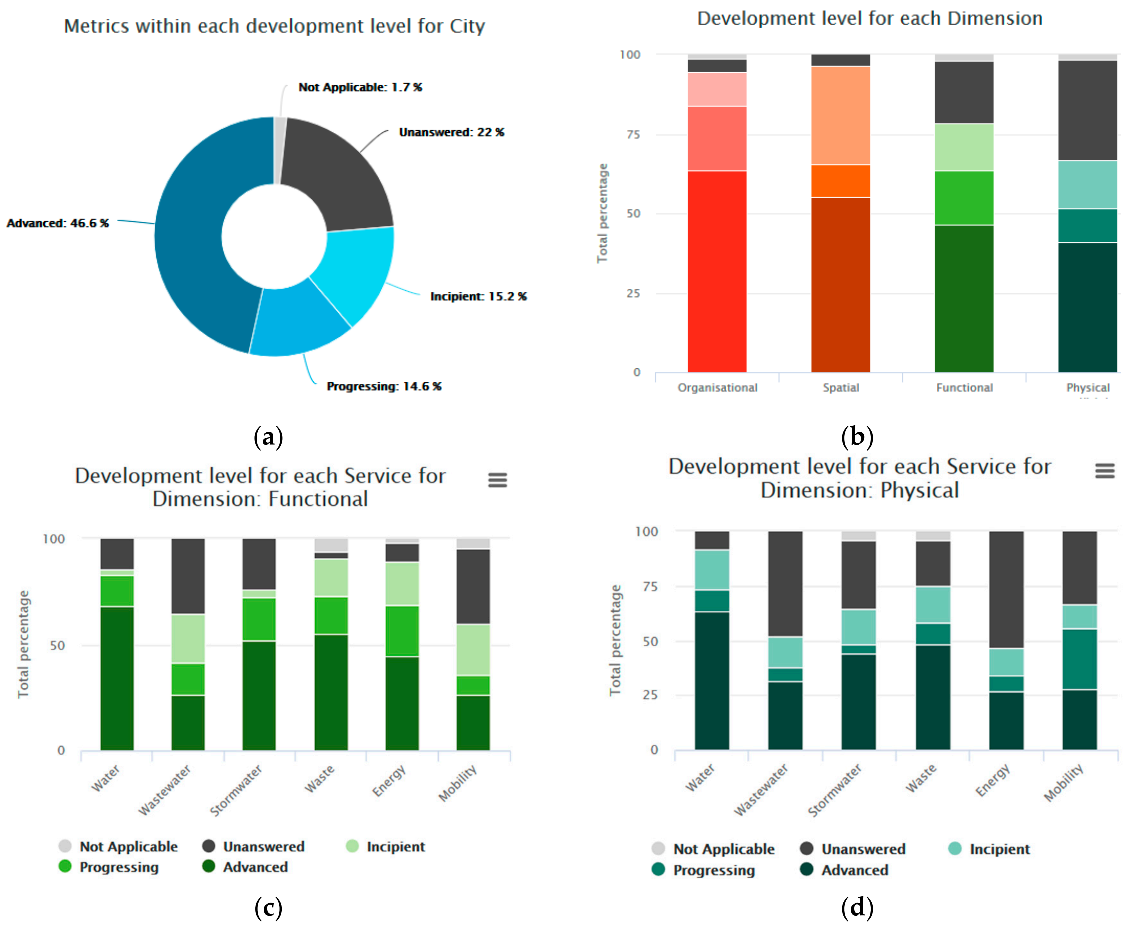

Figure 4. Barcelona resilience assessment results for flooding: (**a**) Overall assessment, (**b**) overall assessment per dimension, (**c**) functional overall assessment per service, (**d**) physical overall assessment per service infrastructure.

The RAF enabled the ability to be realistic with the resilience level of city services. It shed light on the state-of-the-art of urban resilience in Barcelona, highlighting those areas where the city works properly and progresses positively to a high degree of preparedness. At the same time, it has helped to determine those aspects where there is still room for improvement and has also given the chance of applying a methodology capable to reach the deepest areas that make up the operation of a city.

3.3. Lisbon

The RAF was applied in Lisbon in order to assess the current level of city resilience to flooding. The application of a structured resilience assessment framework enables the identification of the resilience criteria, objectives, services and city dimensions with major accomplishments, setbacks or opportunities for improvement. Therefore, it supports identification of resilience measures and development of strategies. Some results are presented in Figure 5. The overall resilience development in the city is advanced in nearly one third of the aspects (Figure 5a). Globally, around a quarter shows progress, meaning that significant steps were already taken, and the city and services are still developing specific aspects. The remainder correspond to incipient, unanswerable or not applicable metrics. Various city services were assessed with more detail, including stormwater, wastewater, energy, mobility and solid waste management.

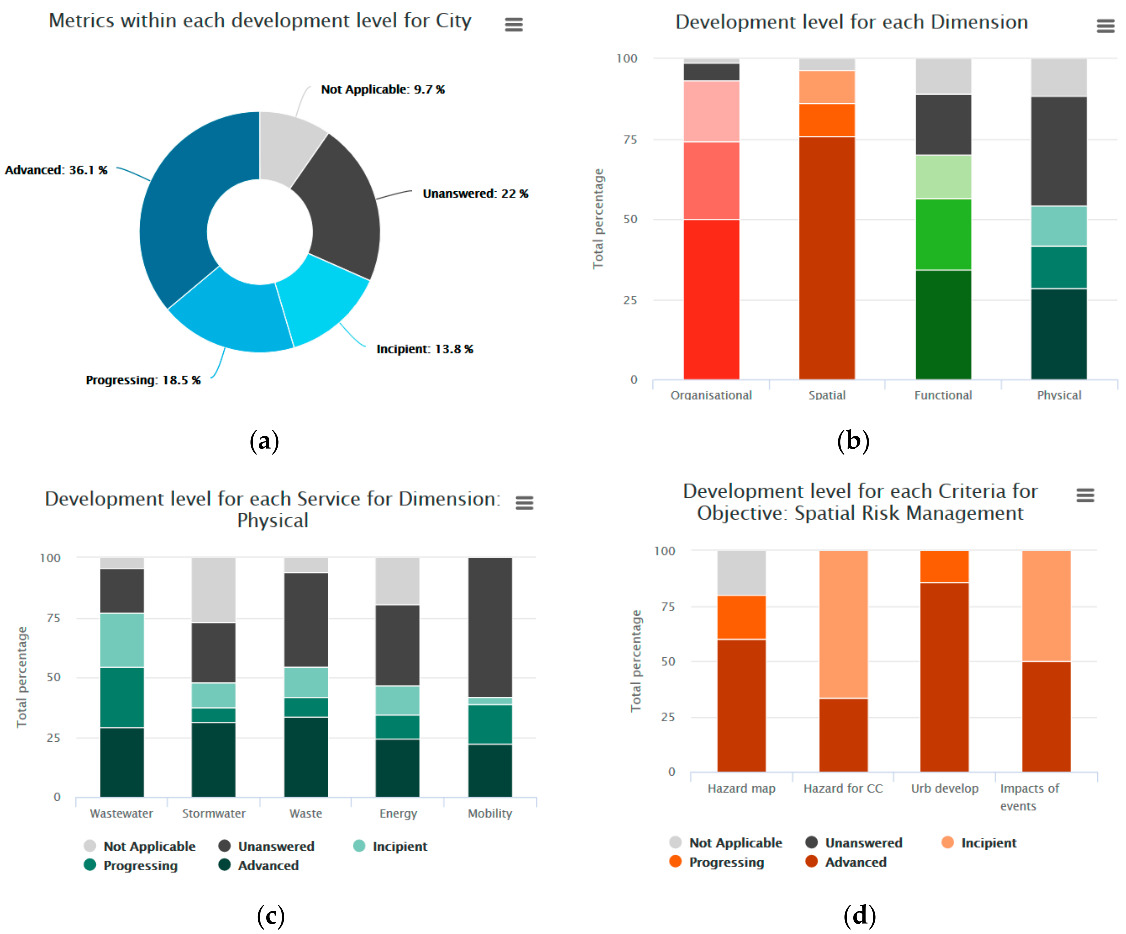

Figure 5. Lisbon resilience assessment results for flooding: (**a**) Overall assessment, (**b**) overall assessment per dimension, (**c**) physical overall assessment per service infrastructure, (**d**) assessment of the objective spatial risk management.

The analysis highlighted a significant advancement in spatial areas more so over physical areas, which were deemed more absent (Figure 5b). The organisational dimension as well as all the services and infrastructures present aspects already having an advanced development level, while still having significant opportunities for improvement. In the mobility service, considering the significant percentage of metrics that were not answered, data may be not be easily applicable to the metrics provided or some lack of information may exist. This is also applicable to the infrastructure assessment of the stormwater, waste and energy services (Figure 5c). Infrastructure resilience to climate change is therefore the main concern on reflection of this. For all services, the contribution of infrastructure to city resilience needs to be more exploited.

The results from the organisational analysis highlight that citizens and communities' awareness and training is one of the aspects that needs further development, followed by the city preparedness for disaster response and for recovery and build back. Engagement with communities is also a dynamic that is not completely to its maximum sufficiency as well as the coordination of financial plans and budgets for resilience.

Concerning the spatial analysis, the provision of protective infrastructures and ecosystems is well developed, while the knowledge on climate change hazard and exposure as well as impacts are highlighted as opportunities to be further developed (Figure 5d).

Generally, there is strong development of strategic planning and there is limited preparedness in the wastewater service for climate change, as well as limited autonomy for the majority of the services, with the exception of the stormwater service. There are, however, some susceptibilities in the realms of reliance upon inter-related services and a lack of understanding of the cascading impacts and interdependencies between those for climate change.

This diagnosis of the main strengths and weaknesses supports the identification of the adequate measures for resilience enhancement to climate change. This assessment is a step up in Lisbon's Climate Change Resilience Process and one diagnosis to be integrated in the ongoing Climate Action Plan of the city.

4. Discussion

By applying the RAF (Sections 2.1 and 2.2) to Bristol, Barcelona and Lisbon (Section 2.3), from the results obtained (Sections 3.1–3.3), it was possible to validate that it provides information on the assessment of the current level of the cities' resilience to climate change with a focus on the water cycle. The framework delivers a structured assessment clearly identifying the work already carried out, translating the strengths of the cities' resilience and which dimensions of resilience they fit into most. This is illustrated by the advanced or progressing values in Figures 3a,b, 4a,b and 5a,b. Besides the assessment of the organisational and spatial dimensions of the city, one particular aspect to emphasize is the identification of the contribution of the urban services to cities' resilience, as evident in Figures 3b, 4b–d and 5b,c. At the same time, the framework highlights the gaps, including limitations on data related to unanswered metrics. It also indicates particular aspects that are lacking, as can be seen by incipient values in Figures 3c,d and 5d, as well as those in more need of further development, given by progressing values in the same figures.

It is evident that the RAF enables to highlight where the cities and respective urban services stand today regarding resilience to climate change, and to identify the most critical aspects to be improved. It should, however, be noted that results of unanswered metrics, corresponding to limitations on data, may be due both to a lack of information or to the alignment in the way existing information is processed in the city with the way the metrics are calculated, as in the Barcelona case (Section 3.2). This last case is likely to occur in cities already using other assessment frameworks. Whenever the framework in use allows to assess the same concerns, i.e., the resilience objectives and criteria corresponding to those of the RAF, they may be used instead. Nevertheless, this provides the challenge to align the RAF with other existing frameworks in this scope. In these circumstances, it is fundamental to clearly identify actual data gaps in the cities and services that need to be filled.

Considering the assignment of a relevance degree described in Section 2.2, it is possible to undertake a stepwise process going into a gradually deeper assessment, depending on the resilience maturity of a city, allowing replicability of the methodology to other cities and services. The framework allows to go into a considerable level of detail investigating many aspects of city resilience quite thoroughly. The whole assessment provides a resilience diagnosis that helps with formulating plans to improve or enhance upon the existing status.

It is feasible to use the RAF to assess diverse hazards such as flooding, combined sewer overflows, drought and heat waves, as it was in the case of Barcelona (Section 2.3.2). The framework may be applicable to provide an overall response regarding the cities' resilience assessment or it may be applied to assess a certain urban service within its scope (Section 2.1).

5. Conclusions

The resilience assessment framework (RAF) herein presented enables to highlight where the cities and respective urban services stand today regarding resilience to climate change, and to identify the most critical aspects to be improved, taking into account both the reference situation and the expected impacts of future climate change scenarios. The diagnosis allows for understanding those aspects that are being tackled properly and also to determine gaps and areas of improvement thanks to the great level of detail of the different dimensions that make up the assessment. It also provides a means to assess resilience progress, therefore contributing to an integrated and forward-looking approach to resilient and sustainable urban development. Additionally, it may facilitate communication among different stakeholders and between different decision levels.

The application of this framework to Bristol, Barcelona and Lisbon cities have demonstrated that the RAF is a tool that provides support to a structured assessment of urban resilience to climate change with a focus on water. Even though it was developed within the scope of climate change and with a focus on the water cycle, replication to other hazards and services is considered on its foundation. Given its different assessment levels, it may be used by any city, service or organisation that intends to undertake a resilience assessment with this scope and focus, regardless of their resilience maturity. The RAF allows to align with the resilience path and integrate the work already in place in the cities and services, as well as to consider the information provided by diverse analysis approaches and tools, already in use or to be used by the city and service managers. Given the adopted structure, an effective and robust implementation requires the involvement of multiple parties, in a collaborative process allowing incorporation of the best available information.

The RAF is a flexible framework allowing further inclusion of additional dimensions, such as social or economic, and of other objectives, criteria and metrics, for the services already addressed. Moreover, it may be strengthened with the incorporation of other services, such as telecommunication, education or health. Other development opportunities are the consideration of other hazards, such as earthquakes, or of other risks.

Author Contributions: M.A.C. supervised this entire study, co-developed the methodology, the framework and the validation, co-analysed the results, drafted manuscript and finalised it. R.S.B. co-developed the methodology, the framework and the validation, co-analysed the results and provided suggestions on the draft manuscript. C.P. co-developed the framework and the validation, co-analysed the results, contributed to the draft manuscript. A.G. coordinated the framework application in Barcelona and contributed to the draft manuscript. J.S. coordinated the framework application in Bristol and contributed to the draft manuscript. M.J.T. coordinated the framework application in Lisbon, provided suggestions on the framework and contributed to the draft manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Resilience Assessment Framework Including Metrics Overview

Table A1. Organisational dimension.

OBJECTIVE **Criterion** **PI**		**PI Unit**
COLLECTIVE ENGAGEMENT AND AWARENESS		
Citizens and communities' engagement		
O01	Community or "grassroots" organisations, networks and training Are grassroots or community organisations participating in pre-event planning and post-event response for each neighbourhood in the city? (UNISDR Scorecard P7.1)	(-)
O02	Civil society links Are civil society organisations engaged? (UNISDR Scorecard D4.1.4 (adapted))	(-)
O03	Engagement of vulnerable groups of the population There is evidence of disaster resilience planning with or for the relevant groups of vulnerable population, and there is a confirmation from those groups of effective engagement. (UNISDR Scorecard D7.2.2 (adapted))	(-)
O04	Citizen engagement techniques How effective is the city at citizen engagement and communications in relation to disaster risk reduction (DRR)? (UNISDR Scorecard P7.4)	(-)
O05	Use of mobile and e-mail "systems of engagement" to enable citizens to receive and give updates before and after a disaster Use of mobile and social computing-enabled systems of engagement. All information before, during and after an event is supported by email, available on mobile devices, supported by alerts on social media, used to enable an in-bound "citizen to government" flow allowing crowd sourcing of data on events and issues. (UNISDR Scorecard D7.4.2 (adapted))	(-)
Citizens and communities' awareness and training		
O06	Public education and awareness Existence and reach of a co-ordinated public relations and education campaign, with structured messaging and channels to ensure hazard, risk and disaster information is disseminated to the public. (UNISDR Scorecard P6.2)	(-)
O07	Training delivery Existence and reach (to all sectors) of training courses covering risk and resilience issues. (UNISDR Scorecard P6.4)	(-)
O08	Drills Do practices and drills involve both the public and professionals? (UNISDR Scorecard P9.7)	(-)
O09	Social networks Are there regular training programmes provided to the most vulnerable and at need populations in the city?	(-)
O10	Validation of effectiveness of education Knowledge of "most probable" risk scenario and knowledge of key response and preparation steps is widespread throughout city. Tested by sample survey. (UNISDR Scorecard D7.4.3 (adapted))	(-)
O11	Consultative planning process Existence and characteristics of formal planning consultative process?	(-)
O12	Planning approval process Characteristics of the planning approval process?	(-)
O13	Public finances Are the objectives of the city Strategy and/or Planning portfolio matched by adequate public finances?	(-)
O14	Financial plan and budget for resilience, including contingency funds Does the city have in place a specific 'ring fenced' (protected) budget, the necessary resources and contingency fund arrangements for local disaster risk reduction (DRR) (mitigation, prevention, response and recovery)? (UNISDR Scorecard P3.2)	(-)

Table A1. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Coordination and communication with stakeholders		
O15	Co-ordination with other government bodies Does the city have a formal mechanism (e.g., Office, Committee, National/Regional Platform) to coordinate actions between city and other international, national, regional or local governments, which ensures integrated and flexible communication and collaboration between them?	(-)
O16	Multi-stakeholder collaboration Does the city have a formal stakeholder engagement programme (including the most socially vulnerable and at need populations)?	(-)
O17	Access and use of digital services In its stakeholder engagement programme, does the city encourage access and use of digital services?	(-)
O18	Collaboration mechanisms In its stakeholder engagement programme, does the city have mechanisms to ensure: a) regular, proactive and inclusive multi-stakeholder collaboration (including the most socially vulnerable and at need populations) (...)	(-)
Resilience-engaged city		
O19	City Master Plan making and implementation Does the city master plan (or relevant strategy/plan) include and localise and/or implement objectives of Agenda 2030?	(-)
O20	City Master Plan monitoring and review Is the City Master Plan periodically monitored and reviewed, ensuring it remains relevant and is properly operational?	(-)
O21	Hazard Assessment Existence of hazard assessment(s) (knowledge of key hazards that the city faces, including likelihood of occurrence)? (UNISDR Scorecard P2.1 (adapted))	(-)
O22	Damage and loss estimation Does risk assessment include estimations of damage and loss from potential disasters, based on current development and future urban and population growth? (UNISDR Scorecard D2.2.2 (adapted))	(-)
O23	Shared understanding of infrastructure risk Is there a shared understanding of risks between the city and various utility providers and other regional and national agencies that have a role in managing infrastructure such as power, water, roads and trains, of the points of stress on the system and city scale risks? (UNISDR Scorecard P2.2)	(-)
O24	Plan for resilience Does the city have a municipally approved resilience plan (strategy or action plan)? And what is its timeframe?	(-)
O25	Plan for resilience and Climate Change Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
O26	Plan integration in the City Master Plan Is the resilience plan integrated with the City Master Plan?	(-)
O27	External support for the resilience plan Is the document being developed by the city alone or with support from INGOs/UN bodies working on the subject?	(-)
O28	Robustness of resilience plan How robust is the resilience plan?	(-)
O29	Resilience Plan monitoring and review Is the resilience plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
O30	Knowledge of resilience scenarios Are there agreed scenarios for resilience (with relevant background information and supporting notes, updated at agreed intervals), setting out city-wide exposure and vulnerability from each hazard, or groups of hazards? (UNISDR Scorecard P2.3 (adapted))	(-)

Table A1. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Resilience-engaged city		
O31	Data sharing Extent to which data on the city's resilience context is shared with other organisations involved with the city's resilience. (UNISDR Scorecard P6.3)	(-)
O32	Integration Is resilience properly integrated with other key city functions/portfolios? (UNISDR Scorecard P1.3)	(-)
O33	Organisation, coordination and participation Is there a multi-agency/sectoral mechanism with appropriate authority and resources to address resilience?	(-)
O34	Critical infrastructure as a priority Is critical infrastructure resilience a city priority? (UNISDR Scorecard P8.1 (adapted))	(-)
O35	Critical infrastructure plan overview Does the city own and implement a critical infrastructure plan or strategy? (UNISDR Scorecard P8.1 (adapted))	(-)
O36	Cascading impacts Is there a collective understanding of potentially cascading failures between different city and infrastructure systems, under different scenarios, and a mapping of such cascading effects is available? (UNISDR Scorecard P2.4 (adapted))	(-)
O37	Learning from others Is the city proactively seeking to exchange knowledge and learn from other cities facing similar challenges? (UNISDR Scorecard P6.6 (adapted))	(-)
CITY PREPAREDNESS		
City preparedness for disaster response		
O38	Early warning Existence of Early Warning System for monitoring, forecasting and doing predictions on hazards (including climate change-related events) (UNISDR Scorecard P9.1 (adapted))	(-)
O39	Reach of warning Percentage of population reachable by early warning systems (UNISDR Scorecard P9.1.1.1 (adapted))	(-)
O40	Communications Would a significant loss of service be expected for a significant proportion of the city in the 'worst case' scenario event? (UNISDR Scorecard P8.6)	(-)
O41	Event management plans Is there a disaster management/preparedness/emergency response plan outlining city mitigation, preparedness and response to local emergencies? (UNISDR Scorecard P9.2)	(-)
O42	Staffing/responder needs Does the responsible disaster management authority have sufficient staffing capacity to support first responder duties in surge event scenario? (UNISDR Scorecard P9.3)	(-)
O43	Equipment and relief supply needs Are equipment and supply needs, as well as the availability of equipment, clearly defined? (UNISDR Scorecard P9.4)	(-)
O44	Definition of human resources, equipment and supply needs, and availability of equipment Has an estimated shortfall in human resources and equipment been identified?	(-)
O45	Existence of agreements If yes, have MOUs - or several ones - been signed, regarding mutual agreements with other cities or private sector resources, in order to cover the detected shortfall?	(-)
O46	Health care Would there be sufficient acute healthcare capabilities to deal with expected major injuries in 'worst case' scenario? (UNISDR Scorecard P8.7)	(-)
O47	Food, shelter, staple goods and fuel supply Would the city be able to continue to feed and shelter its population post-event? (UNISDR Scorecard P9.5)	(-)
O48	Interoperability and interagency working Is there an emergency operations' centre, with participation from all agencies, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6)	(-)

Table A1. *Cont.*

OBJECTIVE Criterion PI		PI Unit
CITY PREPAREDNESS		
City preparedness for disaster response		
O49	Existence of civil society focal points for citizens Existence of volunteers and civil society organisations acting as focal points for citizens after an event, and regularly thereafter, to confirm safety issues, needs etc.	(-)
O50	Social connectedness and neighbourhood cohesion What is the estimated percentage of population that would be contacted by volunteers, within the 12 hours following an event and regularly thereafter? (UNISDR Scorecard D7.2.1 (adapted))	(%)
City preparedness for climate change		
O51	Management plans for climate-related events Does the city have a plan addressing climate-related events, either consisting of a specific document or integrated into the city's planning portfolio?	(-)
O52	Implementation of management plans for climate-related events If existing, is this document being implemented through defined standard operational procedures?	(-)
O53	Management plans for climate-related events monitoring and review If existing, is this document being monitored and reviewed in less than a 5-year interval?	(-)
O54	Knowledge of exposure and vulnerability for climate change scenarios Are there agreed climate change scenarios setting out city-wide exposure and vulnerability from each hazard, or groups of hazards? (UNISDR Scorecard P2.3 (adapted))	(-)
O55	City status when addressing contribution to climate change Comparing to the mean GHG emission per inhabitant that was considered to elaborate the official RCP scenarios, what are the current city's emissions?	(-)
O56	City commitment with mitigation of climate change effects Has the city signed any formal agreement in order to reach an established mitigation target for GHG reduction by 2050, when comparing to 1990 values?	(%)
O57	Planning for mitigation of climate change effects Are the mitigation targets for GHG (emission reduction by 2050) being considered in the city plans and being enforced in new projects?	(-)
City preparedness for recovery and build back		
O58	Post event recovery planning—pre event Is there a strategy or process in place for post-event recovery and reconstruction, including economic reboot, societal aspects etc.? (UNISDR Scorecard P10.1)	(-)
O59	Coordination of post event recovery Is the coordinating body for all post-disaster processes identified and structured, including the distribution of roles and responsibilities between relevant organisations? (UNISDR Scorecard D9.6.3 (adapted))	(-)
O60	Lessons learnt Do post-event assessment processes include failure analysis?	(-)
O61	Learning loops If yes, does this process allow to capture lessons learned, which then feed into design and delivery of rebuilding projects? (UNISDR Scorecard P10.2 (adapted))	(-)
O62	Insurance What level of insurance cover exists in the city, across all sectors - business and community? (UNISDR Scorecard P3.3)	(-)
O63	Damage and loss post-event assessment Does the city have a system in place to provide Post-Disaster Needs Assessment?	(-)
O64	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)

Table A1. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Availability and access to basic services		
O65	Water supply Percentage of households with access to safe drinking water distribution.	(%)
O66	Wastewater collection Percentage of households served by wastewater collection.	(%)
O67	Wastewater treatment Provision of adequate treatment to wastewater through wastewater treatment plant.	(-)
O68	Urban waste collection Percentage of population served by regular solid waste collection (having waste picked up within 200 m from households, by a legally established entity, on at least a weekly basis).	(%)
O69	Urban waste treatment Provision of adequate treatment to solid waste through recovery methods or disposal in landfill?	(-)
O70	Urban electrical energy network Percentage of households with regular connection to the electricity network.	(%)
O71	Urban electrical energy alternative source Estimated percentage of households connected to alternative sources of electricity.	(%)
O72	Urban gas energy network Percentage of households with regular access to the gas distribution network.	(%)
O73	Urban mobility accessing collective transportation Percentage of population living less than 500 m. from any type of public stop, including trains, subway, tram, bus transportation.	(%)
O74	Urban cycling mobility Is there a public plan/strategy to develop cycling paths in the city or expend the existing network?	(-)

Table A2. Spatial dimension.

OBJECTIVE **Criterion** **PI**		**PI Unit**
SPATIAL RISK MANAGEMENT		
General hazard and exposure mapping		
S01	Presentation process for risk information Do clear hazard maps and data on risk exist? (UNISDR Scorecard P2.5 (adapted))	(-)
S02	Update process for risk information If yes, are these maps regularly updated? (UNISDR Scorecard P2.5 (adapted))	(-)
S03	Knowledge of exposure and vulnerability Existence of scenarios setting out city-wide exposure and vulnerability from each hazard level. (UNISDR Scorecard D2.2.1)	(-)
S04	Scenarios and update process for risk information Risk scenarios are updated at least every three years for the following. (UNISDR Scorecard D2.5.1 (adapted))	(-)
S05	Damage and loss estimation Damage and loss aspects taken into account by risk assessments for key identified scenarios. (UNISDR Scorecard D2.2.2)	(-)
Hazard and exposure for climate change		
S06	Potential population at risk of displacement for climate change scenarios Percentage of population at risk of displacement for three months or longer according to climate change scenarios. (UNISDR Scorecard D4.1.1 (adapted))	(-)
S07	Urban footprint at risk for climate change scenarios Percentage of urban footprint at risk, according to climate change scenarios.	(-)
S08	Economic activity at risk for climate change scenarios Percentage of economic activity at risk from climate change scenarios. (UNISDR Scorecard D4.1.2.1 (adapted))	(-)

Table A2. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Resilient urban development		
S09	Land use zoning and planning Is the land use plan - including zoning - informed by risk scenarios?	(-)
S10	Land use plan monitoring and review Is this plan regularly monitored and reviewed? (UNISDR Scorecard P4.1 (adapted))	(-)
S11	Land use zoning implementation Extent to which land use zoning is implemented in the city and complied with. (UNISDR Scorecard D4.4.1 (adapted))	(-)
S12	New urban development Is there a policy promoting physical measures in new development that enhance resilience to one or multiple hazards? (UNISDR Scorecard P4.2 (adapted))	(-)
S13	Urban design solutions that increase resilience Does the city implement urban design solutions tasked to improve resilience? (UNISDR Scorecard D4.2.1 (adapted))	(-)
S14	Building codes and standards Do building codes or standards exist, and do they address specific known hazards and risks for the city? Are these standards regularly updated? (UNISDR Scorecard P4.3)	(-)
S15	Application of building codes Implementation of building codes on relevant structures, certified as such by a 3rd party. (UNISDR Scorecard D4.4.2)	(-)
Impacts of climate-related event		
S16	Human loss in the last events Human impact of the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
S17	Damages in urban footprint in the last events Impact on urban footprint of the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS		
Protective infrastructures and ecosystems services		
S18	Existing protective infrastructure Is existing protective infrastructure designed and built according to risk information? (UNISDR Scorecard P8.2 (adapted))	(-)
S19	New protective infrastructure Is new protective infrastructure (in design or construction process) under development and consistent with best practice (for asset design, building and management, based on relevant risk information)?	(-)
S20	Maintenance of protective infrastructure Is protective infrastructure regularly maintained?	(-)
S21	Awareness and understanding of ecosystem services/functions Beyond just an awareness of the natural assets, does the city understand the functions that this natural capital provides for the city? (UNISDR Scorecard P5.1)	(-)
S22	Awareness of the role that assets that provide ecosystem services play in the city's resilience Assets that provide ecosystem services are specifically identified and managed as critical assets?	(-)
S23	Trends in ecosystem services health Change in health, extent or benefit of each ecosystem service in last 5 years. (UNISDR Scorecard D5.1.2)	(-)

Table A2. *Cont.*

OBJECTIVE Criterion PI		PI Unit
PROVISION OF PROTECTIVE INFRASTRUCTURES AND ECOSYSTEMS		
Protective infrastructures and ecosystems services		
S24	Maintenance of ecosystem services Are ecosystem services specifically maintained and annually monitored on a defined set of key health/performance indicators?	(-)
S25	Availability of green and blue infrastructures Estimated green and blue area per inhabitant.	(m^2/inhabitant)
S26	Integration of green and blue infrastructure into city policy and projects Is green and blue infrastructure being promoted on major urban development and infrastructure projects through policy?	(-)
Dependence and autonomy regarding other services considering climate change		
S27	Critical services dependence of protective infrastructures and ecosystems under climate change scenarios Critical services (CS -RESCCUE services) dependence of protective infrastructures and ecosystems under climate change scenarios.	(-)
S28	Autonomy from other services under climate change scenarios Protective infrastructure and ecosystems autonomy regarding critical services (CS -RESCCUE services) loss under climate change scenarios.	(-)
S29	Transboundary environmental issues Is the city aware of ecosystem services being provided to the city from natural capital beyond its administrative borders? Are agreements in place with neighbouring administrations to support the protection and management of these assets? (UNISDR Scorecard P5.3)	(-)

Table A3. Functional dimension for the Water Service.

OBJECTIVE Criterion PI		PI Unit
WATER SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FWts01	Water service strategic plan making and implementation Does the service have a strategic plan and is it implemented? (UNISDR Scorecard P1.1 (adapted))	(-)
FWts02	Plan alignment with the City Master Plan If yes, is the plan aligned with the city main planning document?	(-)
FWts03	Service plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FWts04	Exchange of information to the city Is there regular exchange of data and information between service and the city concerning the review of planning documents?	(-)
FWts05	Land use zoning compliance Do the service-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged service		
FWts06	Resilience in water service strategy and alignment with City Master Plan Does the service have a resilience plan (either as an autonomous action plan or as a strategy included in the service's strategic plan) and what is its timeframe?	(-)
FWts07	Service strategic plan for resilience and CC Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
FWts08	Service financial plan and budget for resilience Do the service financial plans have dedicated allocations for resilience-building actions including disaster risk reduction (DRR))?	(-)
FWts09	Water service business continuity Do business continuity plans exist?	(-)
FWts10	Co-ordination with other water services in the city Is there any coordination mechanism in place with other water services/entities either at municipal or metropolitan level?	(-)
FWts11	Learning from other water services Is there any knowledge exchange with other services?	(-)

Table A3. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Risk management		
FWts12	Risk information related to the water service Do specific service plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to the service and are regularly updated?	(-)
FWts13	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FWts14	Expected water supply interruptions, not caused by water quality problems, in the city area according to CC scenarios Percentage of the city area expected to be affected by water supply interruptions exceeding 6 h, not caused by water quality problems, according to climate change scenarios.	(% city area)
FWts15	Expected water supply interruptions caused by water quality problems, in the city area according to CC scenarios Percentage of the city area expected to be affected by interruptions exceeding 6 h, caused by water quality problems, according to climate change scenarios.	(% city area)
FWts16	Expected water supply interruptions, not caused by water quality problems, for sensitive customers according to CC scenarios % of sensitive customers expected to be affected by water supply interruptions exceeding 6 h, not caused by water quality problems, according to climate change scenarios.	(% sensitive customers)
FWts17	Expected water supply interruptions caused by water quality problems, for sensitive customers according to CC scenarios % of sensitive customers expected to be affected by interruptions exceeding 6 h, caused by water quality problems, according to climate change scenarios.	(% sensitive customers)
FWts18	Expected water supply interruptions, not caused by water quality problems, for other services according to CC scenarios % of customers of other services expected to be affected by water supply interruptions exceeding 6 h, not caused by water quality problems, according to climate change scenarios.	(% customers other services)
FWts19	Expected water supply interruptions caused by water quality problems, for other services according to CC scenarios % of customers of other services expected to be affected by interruptions exceeding 6 h, caused by water quality problems, according to climate change scenarios.	(% customers other services)
FWts20	Expected water supply interruptions, not caused by water quality problems, for households according to CC scenarios % of households expected to be affected by water supply interruptions exceeding 6 h, not caused by water quality problems, according to climate change scenarios.	(% households)
FWts21	Expected water supply interruptions caused by water quality problems, for households according to CC scenarios % of households expected to be affected by interruptions exceeding 6 h, caused by water quality problems, according to climate change scenarios.	(% households)
FWts22	Expected total duration of water supply interruption, not caused by water quality problems, according to CC scenarios Total duration (days) of expected water supply interruption, not caused by water quality problems, according to climate change scenarios.	(Days)
FWts23	Expected total duration of water supply interruption, caused by water quality problems, according to CC scenarios Total duration (days) of expected water supply interruption, caused by water quality problems, according to climate change scenarios.	(Days)

Table A3. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Reliable service		
FWts24	Water supply interruptions, not caused by water quality problems, in the city area last year Percentage of the city area affected by water supply interruptions exceeding 6 h, not caused by water quality problems, last year.	(% city area)
FWts25	Water supply interruptions caused by water quality problems, in the city area last year Percentage of the city area affected by water supply interruptions exceeding 6 h, caused by water quality problems, last year.	(% city area)
FWts26	Water supply interruptions, not caused by water quality problems, for sensitive customers last year % of sensitive customers affected by water supply interruptions exceeding 6 h, not caused by water quality problems, last year.	(% sensitive customers)
FWts27	Water supply interruptions caused by water quality problems, for sensitive customers last year % of sensitive customers affected by water supply interruptions exceeding 6 h, caused by water quality problems, last year.	(% sensitive customers)
FWts28	Water supply interruptions, not caused by water quality problems, for other services last year % of customers of other services affected by water supply interruptions exceeding 6 h, not caused by water quality problems, last year.	(% customers other services)
FWts29	Water supply interruptions caused by water quality problems, for other services last year % of customers of other services affected by water supply interruptions exceeding 6 h, caused by water quality problems, last year.	(% customers other services)
FWts30	Water supply interruptions, not caused by water quality problems, for households last year % of households affected by water supply interruptions exceeding 6 h, not caused by water quality problems, last year.	(% households)
FWts31	Water supply interruptions caused by water quality problems, for households last year % of households affected by water supply interruptions exceeding 6 h, caused by water quality problems, last year.	(% households)
FWts32	Total duration of water supply interruption, not caused by water quality problems, last year Total duration (days) of water supply interruption, not caused by water quality problems, last year.	(Days)
FWts33	Total duration of water supply interruption, caused by water quality problems, last year Total duration (days) of water supply interruption, caused by water quality problems, last year.	(Days)
FWts34	Water losses last year Water losses last year (water loss volume in the supply system/(total pipe length × 365))	(m^3/(km.day))
Flexible service		
FWts35	Water uses % of drinking water being used for irrigation, street cleaning, firefighting, or other public uses.	(% drinking water)
FWts36	Water sources Which types of water supply sources are being used in the city?	(-)
FWts37	Water sources location Where are the city's water supply sources located?	(-)
FWts38	Service management Services are appropriately managed, i.e., technological tools are used, existing competences are adequate, and a command chain is at place?	(-)

Table A3. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
AUTONOMOUS WATER SERVICE		
Service importance to the city		
FWts39	Stakeholders perception Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes quantify the service score from stakeholder perception.	(-)
FWts40	Cascading impacts Is there an understanding of potentially cascading failures between different services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FWts41	Critical services dependence on water service according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the water service, based on climate change scenarios?	(-)
FWts42	Water services autonomy from other critical services according to CC scenarios To what extent is the water service dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)
WATER SERVICE PREPAREDNESS		
Service preparedness for disaster response		
FWts43	Water service event management plans Is there a disaster management/preparedness/emergency response plan outlining service mitigation, preparedness and response to local emergencies? (UNISDR Scorecard P9.2 (adapted))	(-)
FWts44	Water services interdepartmental collaboration for emergency Is there an emergency operations' centre, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6 (adapted))	(-)
FWts45	Water services early warning Does the service have a plan or standard operating procedure to act on early warnings and forecasts? Is the city warned by this system? (UNISDR Scorecard P9.1 (adapted))	(-)
FWts46	Water service drills Are practices and drills carried out internally and periodically?	(-)
Service preparedness for climate change		
FWts47	Service commitment with mitigation of CC effects Is the service committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FWts48	Existence of agreed CC scenarios and alignment with the city CC scenarios Are there agreed climate change scenarios, setting out service exposure and vulnerability, from each hazard level? Are they aligned with the city-wide climate change scenarios?	(-)
FWts49	Knowledge of exposure and service vulnerability for CC scenarios The analysis of exposure and service vulnerability for climate change scenarios addresses: a) People (. . .)	(-)
FWts50	Service planning for adaptation to CC Is adaptation to climate change being considered in the service plans and enforced in new projects?	(-)
FWts51	Implemented measures to address CC mitigation and adaptation What type of measures has the service implemented to address climate change mitigation and adaptation?	(-)
FWts52	Planned measures to address CC mitigation and adaptation What type of measures is the service planning to implement to address climate change mitigation and adaptation?	(-)
FWts53	Equipment capacity of the service Has the service adequate equipment capacity, in normal and emergency circumstances?	(-)
FWts54	Staffing capacity of the service Has the service adequate staffing capacity, in normal and emergency circumstances?	(-)

Table A3. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Service preparedness for recovery and build back		
FWts55	Water service CC recovery planning Is there a strategy or process in place for post-event service recovery and reconstruction? (UNISDR Scorecard P10.1)	(-)
FWts56	Water service damage and loss post-event assessment Does the service have a system in place to provide Post-Disaster Needs Assessment?	(-)
FWts57	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)
FWts58	Water supply interruption, not caused by water quality problems, in the city area in the last relevant climate-related event Percentage of the city area affected by water supply interruptions exceeding 6 h, not caused by water quality, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FWts59	Water supply interruptions caused by water quality problems, in the city area, in the last relevant climate-related event Percentage of the city area affected by water supply interruptions exceeding 6 h, caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FWts60	Water supply interruptions, not caused by water quality problems, for sensitive customers in the last relevant climate-related event % of sensitive customers affected by water supply interruptions exceeding 6 h, not caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FWts61	Water supply interruptions caused by water quality problems, for sensitive customers in the last relevant climate-related event % of sensitive customers affected by water supply interruptions exceeding 6 h, caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FWts62	Water supply interruptions, not caused by water quality problems, for other services in the last relevant climate-related event % of customers of other services affected by water supply interruptions exceeding 6 h, not caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FWts63	Water supply interruptions caused by water quality problems, for other services in the last relevant climate-related event % of customers of other services affected by water supply interruptions exceeding 6 h, caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FWts64	Water supply interruptions, not caused by water quality problems, for households in the last relevant climate-related event % of households affected by water supply interruptions exceeding 6 h, not caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FWts65	Water supply interruptions caused by water quality problems, for households in the last relevant climate-related event % of households affected by water supply interruptions exceeding 6 h, caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FWts66	Total duration of water supply interruption, caused by water quality problems, in the last relevant climate-related event Days of water supply interruption, not caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FWts67	Total duration of water supply interruption, caused by water quality problems in the last relevant climate-related event Days of water supply interruption, caused by water quality problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FWts68	Water service lessons learnt and learning loops Are service-specific processes in place for lessons learnt, including failure analysis? If yes, are service-specific plans informed by them?	(-)
FWts69	Insurance What level of insurance cover exists in the service?	(-)

Table A4. Functional dimension for Wastewater Service.

OBJECTIVE Criterion PI		PI Unit
WASTEWATER SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FWwt01	Wastewater service strategic plan making and implementation Does the service have a strategic plan and is it implemented? (UNISDR Scorecard P1.1 (adapted))	(-)
FWwt02	Plan alignment with the City Master Plan If yes, is the plan aligned with the city main planning document?	(-)
FWwt03	Service plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FWwt04	Exchange of information to the city Is there regular exchange of data and information between service and the city concerning the review of planning documents?	(-)
FWwt05	Land use zoning compliance Do the service-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged service		
FWwt06	Resilience in wastewater service strategy and alignment with City Master Plan Does the service have a resilience plan (either as an autonomous action plan or as a strategy included in the service's strategic plan) and what is its timeframe?	(-)
FWwt07	Service strategic plan for resilience and CC Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
FWwt08	Service financial plan and budget for resilience Do the service financial plans have dedicated allocations for resilience-building actions (including disaster risk reduction (DRR))?	(-)
FWwt09	Wastewater service business continuity Do business continuity plans exist?	(-)
FWwt10	Co-ordination with other wastewater services in the city Is there any coordination mechanism in place with other wastewater services/entities either at municipal or metropolitan level?	(-)
FWwt11	Learning from other wastewater services Is there any knowledge exchange with other services?	(-)
Risk management		
FWwt12	Risk information related to the wastewater service Do specific service plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to the service and are regularly updated?	(-)
FWwt13	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FWwt14	Expected wastewater flooding in the city area according to CC scenarios Percentage of the city area expected to be affected by flooding due to wastewater collection interruption, according to climate change scenarios.	(% city area)
FWwt15	Expected wastewater treatment failures in the city area according to CC scenarios Percentage of the city area expected to be affected by wastewater treatment failures, according to climate change scenarios.	(% city area)

Table A4. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Risk management		
FWwt16	Expected wastewater flooding in sensitive customers according to CC scenarios % of sensitive customers expected to be affected by flooding due to wastewater collection interruption, according to climate change scenarios.	(% sensitive customers)
FWwt17	Expected wastewater discharges, due to failure in wastewater service to ecosystem services according to CC scenarios Number of expected wastewater discharges into ecosystems services due to wastewater service interruption, according to climate change scenarios.	(-)
FWwt18	Expected wastewater flooding in other services according to CC scenarios % of customers of other services expected to be affected by flooding due to wastewater collection interruption, according to climate change scenarios.	(% customers other services)
FWwt19	Expected wastewater flooding in households according to CC scenarios % of households expected to be affected by flooding due to wastewater collection interruption, according to climate change scenarios.	(% households)
FWwt20	Expected total duration of wastewater flooding period according to CC scenarios Total duration (days) of expected wastewater flooding due to wastewater collection interruption, according to climate change scenarios.	(Days)
FWwt21	Expected total duration of wastewater treatment failure period according to CC scenarios Total duration (days) of expected wastewater treatment failures, according to climate change scenarios.	(Days)
Reliable service		
FWwt22	Wastewater flooding in the city area last year Percentage of the city area affected by flooding due to wastewater collection interruption, last year.	(% city area)
FWwt23	Wastewater treatment failures in the city area in the city area last year Percentage of the city area affected by wastewater treatment failures, last year.	(% city area)
FWwt24	Wastewater flooding in sensitive customers last year % of sensitive customers affected by flooding due to wastewater collection interruption, last year.	(% sensitive customers)
FWwt25	Wastewater discharges, due to failure in wastewater service, to ecosystem services last year Number of wastewater discharges into ecosystems services due to wastewater service interruption, last year.	(-)
FWwt26	Wastewater flooding in other services last year % of customers of other services affected by flooding due to wastewater collection interruption, last year.	(% customers other services)
FWwt27	Wastewater effective treatment in the city area last year Percentage of wastewater that was collected and safely treated, last year.	(%)
FWwt28	Wastewater flooding in households last year % of households affected by flooding due to wastewater collection interruption, last year.	(% households)
FWwt29	Total duration of wastewater flooding period last year Total duration (days) of wastewater flooding, last year.	(Days)
FWwt30	Total duration of wastewater treatment failure period last year Total duration (days) of wastewater treatment failure, last year.	(Days)
FWwt31	Estimated undue inflows into wastewater system last year Undue inflows (e.g., stormwater, industrial, saline, water supply inflows) into the system last year (undue wastewater inflow volume in the collection system/(total pipe length × 365)).	(m^3/(km.day))

Table A4. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Flexible service		
FWwt32	Treated wastewater uses Percentage of treated wastewater being recycled or reused (for e.g., irrigation, urban cleaning, firefighting).	(% treated wastewater)
FWwt33	Wastewater disposal Which solutions for wastewater disposal are used in the city?	(-)
FWwt34	Wastewater disposal location Where are the city's wastewater disposal points located?	(-)
FWwt35	Service management Services are appropriately managed, i.e., technological tools are used, existing competences are adequate, and a command chain is in place?	(-)
AUTONOMOUS WASTEWATER SERVICE		
Service importance to the city		
FWwt36	Stakeholders perception Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes quantify the service score from stakeholder perception.	(-)
FWwt37	Cascading impacts Is there an understanding of potentially cascading failures between different services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FWwt38	Critical services dependence on wastewater service according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the wastewater service, based on climate change scenarios?	(-)
FWwt39	Wastewater services autonomy from other critical services according to CC scenarios To what extent is the wastewater service dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)
WASTEWATER SERVICE PREPAREDNESS		
Service preparedness for disaster response		
FWwt40	Wastewater service event management plans Is there a disaster management/preparedness/emergency response plan outlining service mitigation, preparedness and response to local emergencies? (UNISDR Scorecard P9.2 (adapted))	(-)
FWwt41	Wastewater services interdepartmental collaboration for emergency Is there an emergency operations' centre, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6 (adapted))	(-)
FWwt42	Wastewater services early warning Does the service have a plan or standard operating procedure to act on early warnings and forecasts? Is the city warned by this system? (UNISDR Scorecard P9.1 (adapted))	(-)
FWwt43	Wastewater service drills Are practices and drills carried out internally and periodically?	(-)
Service preparedness for climate change		
FWwt44	Service commitment with mitigation of CC effects Is the service committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FWwt45	Existence of agreed CC scenarios and alignment with the city CC scenarios Are there agreed climate change scenarios, setting out service exposure and vulnerability, from each hazard level? Are they aligned with the city-wide climate change scenarios?	(-)
FWwt46	Knowledge of exposure and service vulnerability for CC scenarios The analysis of exposure and service vulnerability for climate change scenarios addresses: a) People (. . .)	(-)
FWwt47	Service planning for adaptation to CC Is adaptation to climate change being considered in the service plans and enforced in new projects?	(-)

Table A4. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Service preparedness for climate change		
FWwt48	Implemented measures to address CC mitigation and adaptation What type of measures has the service implemented to address climate change mitigation and adaptation?	(-)
FWwt49	Planned measures to address CC mitigation and adaptation What type of measures is the service planning to implement to address climate change mitigation and adaptation?	(-)
FWwt50	Equipment capacity of the service Has the service adequate equipment capacity, in normal and emergency circumstances?	(-)
FWwt51	Staffing capacity of the service Has the service adequate staffing capacity, in normal and emergency circumstances?	(-)
Service preparedness for recovery and build back		
FWwt52	Wastewater service CC recovery planning Is there a strategy or process in place for post-event service recovery and reconstruction? (UNISDR Scorecard P10.1)	(-)
FWwt53	Wastewater service damage and loss post-event assessment Does the service have a system in place to provide Post-Disaster Needs Assessment?	(-)
FWwt54	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)
FWwt55	Wastewater flooding in the city area in the last relevant climate-related event Percentage of the city area affected by flooding due to wastewater collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FWwt56	Wastewater treatment failures in the city area in the last relevant climate-related event Percentage of the city area affected by wastewater treatment failures, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FWwt57	Wastewater flooding in sensitive customers in the last relevant climate-related event % of sensitive customers affected by flooding due to wastewater collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FWwt58	Wastewater discharges, due to failure in wastewater service, to ecosystem services in the last relevant climate-related event Number of wastewater discharges into ecosystems services due to wastewater collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario	(-)
FWwt59	Wastewater flooding for other services in the last relevant event % of customers of other services affected by flooding due to wastewater collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FWwt60	Wastewater effective treatment in the city area in the last relevant climate-related event Percentage of wastewater that was collected and safely treated, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
FWwt61	Wastewater flooding in households in the last relevant climate-related event % of households affected by flooding due to wastewater collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FWwt62	Total duration of wastewater flooding period in the last relevant climate-related event Days of wastewater flooding, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A4. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Service preparedness for recovery and build back		
FWwt63	Total duration of wastewater treatment failure period in the last relevant climate-related event Days of wastewater treatment failure, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FWwt64	Wastewater service lessons learnt and learning loops Are service-specific processes in place for lessons learnt, including failure analysis? If yes, are service-specific plans informed by them?	(-)
FWwt65	Insurance What level of insurance cover exists in the service?	(-)

Table A5. Functional resilience assessment framework of the Stormwater Service.

OBJECTIVE Criterion PI		PI Unit
STORMWATER SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FSwt01	Stormwater service strategic plan making and implementation Does the service have a strategic plan and is it implemented? (UNISDR Scorecard P1.1 (adapted))	(-)
FSwt02	Plan alignment with the City Master Plan If yes, is the plan aligned with the city main planning document?	(-)
FSwt03	Service plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FSwt04	Exchange of information to the city Is there regular exchange of data and information between service and the city concerning the review of planning documents?	(-)
FSwt05	Land use zoning compliance Do the service-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged service		
FSwt06	Resilience in stormwater service strategy and alignment with City Master Plan Does the service have a resilience plan (either as an autonomous action plan or as a strategy included in the service's strategic plan) and what is its timeframe?	(-)
FSwt07	Service strategic plan for resilience and CC Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
FSwt08	Service financial plan and budget for resilience Do the service financial plans have dedicated allocations for resilience-building actions (including disaster risk reduction (DRR))?	(-)
FSwt09	Stormwater service business continuity Do business continuity plans exist?	(-)
FSwt10	Co-ordination with other stormwater services in the city Is there any coordination mechanism in place with other stormwater services/entities either at municipal or metropolitan level?	(-)
FSwt11	Learning from other stormwater services	(-)

Table A5. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
	Is there any knowledge exchange with other services?	
Risk management		
FSwt12	Risk information related to the stormwater service Do specific service plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to the service and are regularly updated?	(-)
FSwt13	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FSwt14	Expected stormwater flooding in the city area according to CC scenarios Percentage of the city area expected to be affected by flooding due to stormwater drainage problems, according to climate change scenarios.	(% city area)
FSwt15	Expected stormwater flooding in sensitive customers according to CC scenarios % of sensitive customers expected to be affected by flooding due to stormwater drainage problems, according to climate change scenarios.	(% sensitive customers)
FSwt16	Expected stormwater flooding in other services according to CC scenarios % of customers of other services expected to be affected by flooding due to stormwater drainage problems, according to climate change scenarios.	(% customers other services)
FSwt17	Expected stormwater flooding in households according to CC scenarios % of households expected to be affected by flooding due to stormwater drainage problems, according to climate change scenarios.	(% households)
FSwt18	Expected total duration of stormwater flooding period according to CC scenarios Total duration (days) of expected stormwater flooding due to stormwater drainage problems, according to climate change scenarios.	(Days)
Reliable service		
FSwt19	Stormwater flooding in the city area last year Percentage of the city area affected by flooding due to stormwater drainage problems, last year.	(% city area)
FSwt20	Stormwater flooding in sensitive customers last year % of sensitive customers affected by flooding due to stormwater drainage problems, last year.	(% sensitive customers)
FSwt21	Stormwater flooding in other services last year % of customers of other services affected by flooding due to stormwater drainage problems, last year.	(% customers other services)
FSwt22	Stormwater flooding in households last year % of households affected by flooding due to stormwater drainage problems, last year.	(% households)
FSwt23	Total duration of stormwater flooding period last year Total duration (days) of stormwater flooding, due to stormwater drainage problems, last year.	(Days)
FSwt24	Estimated undue inflows into stormwater system last year Undue inflows (e.g., wastewater, industrial, saline, water supply inflows) into the system last year (undue wastewater inflow volume in the collection system/(total pipe length × 365)).	(m^3/(km.day))

Table A5. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Flexible service		
FSwt25	Treated stormwater uses % of collected stormwater being recycled or reused (for e.g., irrigation, urban cleaning, firefighting).	(% treated stormwater)
FSwt26	Stormwater disposal Which solutions for stormwater disposal are used in the city?	(-)
FSwt27	Stormwater disposal location Where are the city's stormwater disposal points located?	(-)
FSwt28	Service management Services are appropriately managed, i.e., technological tools are used, existing competences are adequate, and a command chain is at place?	(-)
AUTONOMOUS STORMWATER SERVICE		
Service importance to the city		
FSwt29	Stakeholders perception Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes quantify the service score from stakeholder perception.	(-)
FSwt30	Cascading impacts Is there an understanding of potentially cascading failures between different services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FSwt31	Critical services dependence on stormwater service according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the stormwater service, based on climate change scenarios?	(-)
FSwt32	Stormwater services autonomy from other critical services according to CC scenarios To what extent is the stormwater service dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)
STORMWATER SERVICE PREPAREDNESS		
Service preparedness for disaster response		
FSwt33	Stormwater service event management plans Is there a disaster management/preparedness/emergency response plan outlining service mitigation, preparedness and response to local emergencies? (UNISDR Scorecard P9.2 (adapted))	(-)
FSwt34	Stormwater services interdepartmental collaboration for emergency Is there an emergency operations' centre, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6 (adapted))	(-)
FSwt35	Stormwater services early warning Does the service have a plan or standard operating procedure to act on early warnings and forecasts? Is the city warned by this system? (UNISDR Scorecard P9.1 (adapted))	(-)
FSwt36	Stormwater service drills Are practices and drills carried out internally and periodically?	(-)

Table A5. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Service preparedness for climate change		
FSwt37	Service commitment with mitigation of CC effects Is the service committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FSwt38	Existence of agreed CC scenarios and alignment with the city CC scenarios Are there agreed climate change scenarios, setting out service exposure and vulnerability, from each hazard level? Are they aligned with the city-wide climate change scenarios?	(-)
FSwt39	Knowledge of exposure and service vulnerability for CC scenarios The analysis of exposure and service vulnerability for climate change scenarios addresses: a) People (…)	(-)
FSwt40	Service planning for adaptation to CC Is adaptation to climate change being considered in the service plans and enforced in new projects?	(-)
FSwt41	Implemented measures to address CC mitigation and adaptation What type of measures has the service implemented to address climate change mitigation and adaptation?	(-)
FSwt42	Planned measures to address CC mitigation and adaptation What type of measures is the service planning to implement to address climate change mitigation and adaptation?	(-)
FSwt43	Equipment capacity of the service Has the service adequate equipment capacity, in normal and emergency circumstances?	(-)
FSwt44	Staffing capacity of the service Has the service adequate staffing capacity, in normal and emergency circumstances?	(-)
Service preparedness for recovery and build back		
FSwt45	Stormwater service CC recovery planning Is there a strategy or process in place for post-event service recovery and reconstruction? (UNISDR Scorecard P10.1)	(-)
FSwt46	Stormwater service damage and loss post-event assessment Does the service have a system in place to provide Post-Disaster Needs Assessment?	(-)
FSwt47	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)
FSwt48	Stormwater flooding in the city area in the last relevant climate-related event Percentage of the city area affected by flooding due to stormwater drainage problems in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FSwt49	Stormwater flooding in sensitive customers in the last relevant climate-related event % of sensitive customers affected by flooding due to stormwater drainage problems in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FSwt50	Stormwater flooding in other services in the last relevant climate-related event % of customers of other services affected by flooding due to stormwater drainage problems in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FSwt51	Stormwater flooding in households in the last relevant climate-related event % of households affected by flooding due to stormwater drainage problems in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FSwt52	Total duration of stormwater flooding in the last relevant climate-related event Days of stormwater flooding due to stormwater drainage problems in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FSwt53	Stormwater service lessons learnt and learning loops Are service-specific processes in place for lessons learnt, including failure analysis? If yes, are service-specific plans informed by them?	(-)
FSwt54	Insurance What level of insurance cover exists in the service?	(-)

Table A6. Functional dimension for Waste Service.

OBJECTIVE **Criterion** **PI**		**PI Unit**
WASTE SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FSlw01	Waste service strategic plan making and implementation Does the service have a strategic plan and is it implemented? (UNISDR Scorecard P1.1 (adapted))	(-)
FSlw02	Plan alignment with the City Master Plan If yes, is the plan aligned with the city main planning document?	(-)
FSlw03	Service plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FSlw04	Exchange of information to the city Is there regular exchange of data and information between service and the city concerning the review of planning documents?	(-)
FSlw05	Land use zoning compliance Do the service-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged service		
FSlw06	Resilience in waste service strategy and alignment with City Master Plan Does the service have a resilience plan (either as an autonomous action plan or as a strategy included in the service's strategic plan) and what is its timeframe?	(-)
FSlw07	Service strategic plan for resilience and CC Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
FSlw08	Service financial plan and budget for resilience Do the service financial plans have dedicated allocations for resilience-building actions (including disaster risk reduction (DRR))?	(-)
FSlw09	Waste service business continuity Do business continuity plans exist?	(-)
FSlw10	Co-ordination with other waste services in the city Is there any coordination mechanism in place with other solid waste services/entities either at municipal or metropolitan level?	(-)
FSlw11	Learning from other waste services Is there any knowledge exchange with other services?	(-)
Risk management		
FSlw12	Risk information related to the waste service Do specific service plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to the service and are regularly updated?	(-)
FSlw13	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FSlw14	Expected solid waste collection interruption in the city area according to CC scenarios. Percentage of the city area expected to be affected by solid waste collection interruptions exceeding 4 days, according to climate change scenarios.	(% city area)
FSlw15	Expected solid waste treatment failure in the city area according to CC scenarios Percentage of the city area expected to be affected by solid waste treatment problems exceeding 4 days, according to climate change scenarios.	(% city area)

Table A6. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Risk management		
FSlw16	Expected solid waste collection interruption of sensitive customers according to CC scenarios % of sensitive customers expected to be affected by solid waste collection interruption exceeding 4 days, according to climate change scenarios.	(% sensitive customers)
FSlw17	Expected solid waste collection interruption for other services according to CC scenarios % of customers of other services expected to be affected by solid waste collection interruption exceeding 4 days, according to climate change scenarios.	(% customers other services)
FSlw18	Expected solid waste collection interruption in households according to CC scenarios % of households expected to be affected by solid waste collection interruption exceeding 4 days, according to climate change scenarios.	(% households)
FSlw19	Expected total duration of solid waste collection interruption period according to CC scenarios Total duration (days) of expected solid waste collection interruption, according to climate change scenario.	(Days)
FSlw20	Expected total duration of solid waste treatment failure period according to CC scenarios Total duration (days) of expected solid waste treatment failure, according to climate change scenarios.	(Days)
Reliable service		
FSlw21	Solid waste collection interruption in the city area last year Percentage of the city area affected by solid waste collection interruptions exceeding 4 days, last year.	(% city area)
FSlw22	Solid waste effective treatment failure in the city area last year Percentage of the city area affected by solid waste treatment problems exceeding 4 days, last year.	(% city area)
FSlw23	Solid waste collection interruption for sensitive customers last year % of sensitive customers affected by solid waste collection interruption exceeding 4 days, last year.	(% sensitive customers)
FSlw24	Solid waste collection interruption for other services, last year % of customers of other services affected by solid waste collection interruption exceeding 4 days, last year.	(% customers other services)
FSlw25	Solid waste effective treatment in the city area last year Percentage of solid waste that was collected and safely treated, last year.	(% safely treated solid waste)
FSlw26	Solid waste collection interruption in households, last year % of households affected by solid waste collection interruption exceeding 4 days, last year.	(% households)
FSlw27	Total duration of solid waste collection interruption period last year Total duration (days) of solid waste collection interruption, last year.	(Days)
FSlw28	Total duration of solid waste treatment failure period last year Total duration (days) of solid waste treatment failure, last year.	(Days)
FSlw29	Estimated undue wastes into solid waste system last year Types of undue wastes into the solid waste system.	(-)
Flexible service		
FSlw30	Treated solid waste recovered % of treated solid waste being recovered (from recycling and reuse, energy recovery, composting …)	(% treated solid waste being recovered)
FSlw31	Solid waste disposal Which solutions for solid waste disposal are used in the city?	(-)
FSlw32	Solid waste disposal location Where are the city's solid waste disposal points located?	(-)
FSlw33	Service management Services are appropriately managed, i.e., technological tools are used, existing competences are adequate, and a command chain is at place?	(-)

Table A6. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
AUTONOMOUS WASTE SERVICE		
Service importance to the city		
FSlw34	Stakeholders perception Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes quantify the service score from stakeholder perception.	(-)
FSlw35	Cascading impacts Is there an understanding of potentially cascading failures between different services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FSlw36	Critical services dependence on solid waste service according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the waste service, based on climate change scenarios?	(-)
FSlw37	Solid waste services autonomy from other critical services according to CC scenarios To what extent is the waste service dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)
WASTE SERVICE PREPAREDNESS		
Service preparedness for disaster response		
FSlw38	Solid waste service event management plans Is there a disaster management/preparedness/emergency response plan outlining service mitigation, preparedness and response to local emergencies? (UNISDR Scorecard 9.2 (adapted))	(-)
FSlw39	Solid waste services interdepartmental collaboration for emergency Is there an emergency operations' centre, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6 (adapted))	(-)
FSlw40	Solid waste services early warning Does the service have a plan or standard operating procedure to act on early warnings and forecasts? Is the city warned by this system? (UNISDR Scorecard P9.1 (adapted))	(-)
FSlw41	Solid waste service drills Are practices and drills carried out internally and periodically?	(-)
Service preparedness for climate change		
FSlw42	Service commitment with mitigation of CC effects Is the service committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FSlw43	Existence of agreed CC scenarios and alignment with the city CC scenarios Are there agreed climate change scenarios, setting out service exposure and vulnerability, from each hazard level? Are they aligned with the city-wide climate change scenarios?	(-)
FSlw44	Knowledge of exposure and service vulnerability for CC scenarios The analysis of exposure and service vulnerability for climate change scenarios addresses: a) People (. . .)	(-)
FSlw45	Service planning for adaptation to CC Is adaptation to climate change being considered in the service plans and enforced in new projects?	(-)
FSlw46	Implemented measures to address CC mitigation and adaptation What type of measures has the service implemented to address climate change mitigation and adaptation?	(-)
FSlw47	Planned measures to address CC mitigation and adaptation What type of measures is the service planning to implement to address climate change mitigation and adaptation?	(-)
FSlw48	Equipment capacity of the service Has the service adequate equipment capacity, in normal and emergency circumstances?	(-)
FSlw49	Staffing capacity of the service Has the service adequate staffing capacity, in normal and emergency circumstances?	(-)
Service preparedness for recovery and build back		
FSlw50	Solid waste service CC recovery planning Is there a strategy or process in place for post-event service recovery and reconstruction? (UNISDR Scorecard 10.1)	(-)
FSlw51	Solid waste service damage and loss post-event assessment Does the service have a system in place to provide Post-Disaster Needs Assessment?	(-)

Table A6. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Service preparedness for recovery and build back		
FSlw52	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)
FSlw53	Solid waste collection interruption in the city area in the last relevant climate-related event % of city area with solid waste collection interruption in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FSlw54	Solid waste effective treatment failure in the city area in the last relevant climate-related event Percentage of the city area affected by solid waste treatment problems, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FSlw55	Solid waste collection interruption in sensitive customers in the last relevant climate-related event % of sensitive customers affected by solid waste collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FSlw56	Solid waste collection interruption for other services in the last relevant climate-related event % of customers of other services affected by solid waste collection interruption in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FSlw57	Solid waste effective treatment in the city area in the last relevant climate-related event Percentage of solid waste that was collected and safely treated in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% solid waste safely treated)
FSlw58	Solid waste collection interruption in households in the last relevant climate-related event % of households affected by solid waste collection interruption in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FSlw59	Total duration of solid waste collection interruption in the last relevant climate-related event Days of solid waste collection interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FSlw60	Total duration of solid waste treatment failure in the last relevant climate-related event Days of solid waste treatment failure, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
FSlw61	Solid waste service lessons learnt and learning loops Are service-specific processes in place for lessons learnt, including failure analysis? If yes, are service-specific plans informed by them?	(-)
FSlw62	Insurance What level of insurance cover exists in the service?	(-)

Table A7. Functional dimension for the Energy Service.

OBJECTIVE **Criterion** **PI**		**PI Unit**
ENERGY SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FEne01	Energy service strategic plan making and implementation Does the service have a strategic plan and is it implemented? (UNISDR Scorecard P1.1 (adapted))	(-)
FEne02	Plan alignment with the City Master Plan If yes, is the plan aligned with the city main planning document?	(-)
FEne03	Service plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FEne04	Exchange of information to the city Is there regular exchange of data and information between service and the city concerning the review of planning documents?	(-)
FEne05	Land use zoning compliance Do the service-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged service		
FEne06	Resilience in energy service strategy and alignment with City Master Plan Does the service have a resilience plan (either as an autonomous action plan or as a strategy included in the service's strategic plan) and what is its timeframe?	(-)
FEne07	Service strategic plan for resilience and CC Does the resilience plan consider climate change (projection, scenarios, impacts, etc.)?	(-)
FEne08	Service financial plan and budget for resilience Do the service financial plans have dedicated allocations for resilience-building actions (including disaster risk reduction (DRR))?	(-)
FEne09	Energy service business continuity Do business continuity plans exist?	(-)
FEne10	Co-ordination with other energy services in the city Is there any coordination mechanism in place with other energy services/entities either at municipal or metropolitan level?	(-)
FEne11	Learning from other energy services Is there any knowledge exchange with other services?	(-)
Risk management		
FEne12	Risk information related to the energy service Do specific service plans include risk information (such as exposure and vulnerability, damage and loss quantification, etc.) related to the service and are regularly updated?	(-)
FEne13	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FEne14	Expected energy outage in the city area according to CC scenarios Percentage of the city area expected to be affected by energy outage exceeding 6 h, according to climate change scenarios.	(% city area)
FEne15	Expected energy outage for sensitive customers according to CC scenarios % of sensitive customers expected to be affected by energy outage exceeding 6 h, according to climate change scenarios.	(% sensitive customers)

Table A7. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Risk management		
FEne16	Expected energy outage for other services according to CC scenarios	(% customers other services)
	% of customers of other services expected to be affected by energy outage exceeding 6 h, according to climate change scenarios.	
FEne17	Expected energy outage for households according to CC scenarios	(% households)
	% of households expected to be affected by energy outage exceeding 6 h, according to climate change scenarios.	
FEne18	Expected total duration of energy outage period according to CC scenarios	(Days)
	Total duration (days) of expected energy outage, according to climate change scenarios.	
Reliable service		
FEne19	Energy outage in the city area last year	(% city area)
	Percentage of the city area affected by energy outage exceeding 6 h last year.	
FEne20	Energy outage for sensitive customers last year	(% sensitive customers)
	% of sensitive customers affected by energy outage exceeding 6 h last year.	
FEne21	Energy outage for other services last year	(% customers other services)
	% of customers of other services affected by energy outage exceeding 6 h last year.	
FEne22	Energy outage in households last year	(% households)
	% of households affected by energy outage exceeding 6 h last year.	
FEne23	Total duration of energy outage period last year	(Days)
	Total duration of energy outage periods last year (days).	
FEne24	Energy losses last year	(-)
	Energy losses last year (rate of electricity losses in distribution networks measured as the ratio between losses and supplies of electricity).	
Flexible service		
FEne25	Alternative energy sources	(% energy from renewable sources)
	% of energy coming from renewable sources.	
FEne26	Energy sources	(-)
	Which energy sources are used in the city?	
FEne27	Energy sources location	(-)
	Where are the city's energy source points located?	
FEne28	Service management	(-)
	Services are appropriately managed, i.e., technological tools are used, existing competences are adequate, and a command chain is at place?	

Table A7. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
AUTONOMOUS ENERGY SERVICE		
Service importance to the city		
FEne29	Stakeholders perception Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes, quantify the service score from stakeholder perception.	(-)
FEne30	Cascading impacts Is there an understanding of potentially cascading failures between different services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FEne31	Critical services dependence on energy service according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the energy service, based on climate change scenarios?	(-)
FEne32	Energy services autonomy from other critical services according to CC scenarios To what extent is the energy service dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)
ENERGY SERVICE PREPAREDNESS		
Service preparedness for disaster response		
FEne33	Energy service event management plans Is there a disaster management/preparedness/emergency response plan outlining service mitigation, preparedness and response to local emergencies? (UNISDR Scorecard P9.2 (adapted))	(-)
FEne34	Energy services interdepartmental collaboration for emergency Is there an emergency operations' centre, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios? (UNISDR Scorecard P9.6 (adapted))	(-)
FEne35	Energy services early warning Does the service have a plan or standard operating procedure to act on early warnings and forecasts? Is the city warned by this system? (UNISDR Scorecard P9.1 (adapted))	(-)
FEne36	Energy service drills Are practices and drills carried out internally and periodically?	(-)
Service preparedness for climate change		
FEne37	Service commitment with mitigation of CC effects Is the service committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FEne38	Existence of agreed CC scenarios and alignment with the city CC scenarios Are there agreed climate change scenarios, setting out service exposure and vulnerability, from each hazard level? Are they aligned with the city-wide climate change scenarios?	(-)
FEne39	Knowledge of exposure and service vulnerability for CC scenarios The analysis of exposure and service vulnerability for climate change scenarios addresses: a) People (. . .)	(-)

Table A7. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Service preparedness for climate change		
FEne40	Service planning for adaptation to CC Is adaptation to climate change being considered in the service plans and enforced in new projects?	(-)
FEne41	Implemented measures to address CC mitigation and adaptation What type of measures has the service implemented to address climate change mitigation and adaptation?	(-)
FEne42	Planned measures to address CC mitigation and adaptation What type of measures is the service planning to implement to address climate change mitigation and adaptation?	(-)
FEne43	Equipment capacity of the service Has the service adequate equipment capacity, in normal and emergency circumstances?	(-)
FEne44	Staffing capacity of the service Has the service adequate staffing capacity, in normal and emergency circumstances?	(-)
Service preparedness for recovery and build back		
FEne45	Energy service CC recovery planning Is there a strategy or process in place for post-event service recovery and reconstruction? (UNISDR Scorecard P10.1)	(-)
FEne46	Energy service damage and loss post-event assessment Does the service have a system in place to provide Post-Disaster Needs Assessment?	(-)
FEne47	Current post-event assessment system If yes, has such system been defined, implemented, tested and historic data is registered?	(-)
FEne48	Energy outage in the city area in the last relevant climate-related event Percentage of city area affected by energy outage exceeding 6 h in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FEne49	Energy outage in sensitive customers in the last relevant climate-related event % of sensitive customers affected by energy outage exceeding 6 h in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% sensitive customers)
FEne50	Energy outage in other services in the last relevant climate-related event % of customers of other services affected by energy outage exceeding 6 h in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% customers other services)
FEne51	Energy outage in households in the last relevant climate-related event % of households affected by energy outage exceeding 6 h in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% households)
FEne52	Total duration of energy outage in the last relevant climate-related event Days of energy outage in the last relevant climate-related event.	(Days)
FEne53	Energy service lessons learnt and learning loops Are service-specific processes in place for lessons learnt, including failure analysis? If yes, are service-specific plans informed by them?	(-)
FEne54	Insurance What level of insurance cover exists in the service?	(-)

Table A8. Functional dimension for the Mobility Service.

OBJECTIVE **Criterion** **PI**		**PI Unit**
MOBILITY SERVICE PLANNING AND RISK MANAGEMENT		
Strategic planning		
FMob01	Mobility service strategic plan making and implementation Existence and implementation of a strategic plan for the mobility in the city. (UNISDR Scorecard P1.1 (adapted))	(-)
FMob02	Characterization of mobility needs The plan includes the characterization of the following population mobility habits: a) Type of mobility solutions used (...)	(-)
FMob03	Mobility plan monitoring and review If existing, is the plan periodically monitored and reviewed, ensuring it remains relevant and operational?	(-)
FMob04	Routes hierarchy characterization The city established a hierarchy of its routes.	(-)
FMob05	Land use zoning compliance Do mobility-specific plans comply with up-to-date land use and zoning regulations?	(-)
Resilience engaged mobility		
FMob06	Resilience in Mobility service strategy Resilience's aspects are included in the mobility plan?	(-)
FMob07	Mobility plan for Climate Change The plan considers climate change (hazards, projections, scenarios, impacts, etc.)?	(-)
FMob08	Budget for resilience The mobility plan has dedicated allocations for resilience-building actions (including disaster risk reduction (DRR))?	(-)
FMob09	Co-ordination with other Mobility services in the city Is there any coordination mechanism in place between mobility services/entities either at municipal or metropolitan level?	(-)
FMob10	Learning from other Mobility services Is there any knowledge exchange with other services?	(-)
Risk management		
FMob11	Risk information related to the Mobility service Does the mobility plan include risk information (such as exposure and vulnerability, identification of higher flow routes, damage and loss quantification, etc.) and is it regularly updated?	(-)
FMob12	Damage and loss estimation Does risk assessment include estimations of damage and loss for agreed climate change scenarios, based on current development and future urban and population growth?	(-)
FMob13	Expected mobility interruption in the city area according to CC scenarios No city area at risk of mobility interruptions exceeding 2 h, due to the most probable scenario, for these services:	(-)
FMob14	Expected mobility interruption in the higher flow routes according to CC scenarios Expected mobility interruption exceeding 2 hours in the higher flow routes according to climate change scenarios.	(-)
FMob15	Expected mobility interruption for population according to CC scenarios No population living in the area expected to be affected by mobility interruption exceeding 2 h, due to the most probable scenario, for these services: a) Road based (...)	(-)
FMob16	Expected mobility interruption for long-distance passengers according to CC scenarios No long-distance passengers expected to be affected by mobility interruption exceeding 2 h, due to the most probable scenario, for these services: a) Road based (...)	(-)
FMob17	Expected mobility interruption period according to CC scenarios Less than 2 h of expected mobility interruption, due to the most probable scenario, for these services: a) Road based (...)	(-)

Table A8. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Reliable mobility		
FMob18	Public transport spatial coverage Public transport is available and covers: a) More than or equal to 80% of the city area (. . .)	(% city area)
FMob19	Public transport daily coverage Public transport is available.	(Hours/day)
FMob20	Mobility interruption in the higher flow routes last year Mobility interruption exceeding 2 hours in the higher flow routes last year.	(-)
FMob21	Mobility interruption in the city area last year Less than 2.5% of the city area with mobility interruptions exceeding 2 h, last year, for these services: a) Road based (. . .)	(-)
FMob22	Mobility interruption for population last year Less than 2.5% of the population living in the area affected by mobility interruption exceeding 2 h, last year, for these services: a) Road based (. . .)	(-)
FMob23	Mobility interruption for long-distance passengers last year Less than 2.5% of the long-distance passengers affected by mobility interruption exceeding 2 h, last year, for these services: a) Road based (. . .)	(-)
FMob24	Total duration of mobility interruption period last year Less than 0.5 days of mobility interruption, last year, for these services: a) Road based (. . .)	(-)
FMob25	Routes with restrictions to circulation of heavy vehicles The city has identified the routes with restriction to the circulation of heavy vehicles.	(-)
FMob26	Routes with restrictions to circulation of medical or emergency vehicles The city has identified the routes with restriction to the circulation of medical or emergency vehicles.	(-)
Flexible mobility		
FMob27	Alternative mobility % of everyday cycling mobility.	(% everyday cycling mobility)
FMob28	City mobility solutions Which solutions for mobility are available in the city?	(-)
FMob29	Modal split for city road-based solutions % share of each road-based solution.	(% share)
FMob30	Long distance mobility solutions Which solutions for long distance mobility are available in the city?	(-)
FMob31	Mobility passenger transference Where are the city's mobility central node points located?	(-)
FMob32	Use of mobility management tools Mobility in the city recurs to the following management tools: a) Traffic lighting is managed in an integrated and automatic way (. . .)	(-)
AUTONOMOUS MOBILITY		
Service importance to the city		
FMob33	Stakeholders perception of city mobility Is there a mechanism to provide service score, based on stakeholders' perception and is it applied? If yes, quantify the service score from stakeholder perception.	(-)
FMob34	Cascading impacts Is there an understanding of potentially cascading failures between different mobility services, under different scenarios? (UNISDR Scorecard P2.4 (adapted))	(-)
Service inter-dependency with other services considering climate change		
FMob35	Critical services dependence on mobility according to CC scenarios To what extent are critical services (CS -RESCCUE services) dependent on the mobility, based on climate change scenarios?	(-)
FMob36	Mobility autonomy from other critical services according to CC scenarios To what extent is the mobility dependent on other critical services (CS -RESCCUE services), based on climate change scenarios?	(-)

Table A8. *Cont.*

OBJECTIVE Criterion PI		PI Unit
MOBILITY PREPAREDNESS		
Mobility preparedness for climate change		
FMob37	Mobility commitment with mitigation of CC effects Is city mobility committed with an established mitigation target regarding reduction of GHG within its strategic planning?	(% reduction GHG)
FMob38	Mobility interruption in the city area in the last relevant climate-related event Percentage of city area affected by mobility interruption exceeding 2 h, in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% city area)
FMob39	Mobility interruption in the higher flow routes in the last relevant climate-related event Mobility interruption exceeded 2 h in higher flow routes in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
FMob40	Mobility interruption for population in the last relevant climate-related event Less than 2.5% of population living in the area affected by mobility interruption exceeding 2 h, in the last climate-related event, with similar or harsher climate variables than the most probable scenario, for these services: a) Road based (. . .)	(-)
FMob41	Mobility interruption for long-distance passengers in the last relevant climate-related event Less than 2.5% of long-distance passengers affected by mobility interruption exceeding 2 h, in the last climate-related event, with similar or harsher climate variables than the most probable scenario, for these services: a) Road based (. . .)	(-)
FMob42	Mobility interruption period in the last relevant climate-related event Less than 2 h that mobility services suffered from interruption, in the last climate-related event, with similar or harsher climate variables than the most probable scenario, for these services: a) Road based (. . .)	(-)

Table A9. Physical dimension for the water infrastructure.

OBJECTIVE Criterion PI		PI Unit
SAFE WATER INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PWts01	Water infrastructure critical assets Are the critical infrastructure assets for service provision identified?	(-)
PWts02	Component importance The identification of infrastructure critical assets is based in the following:	(-)
PWts03	Water infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PWts04	Exchange of information Is there a regular exchange of information regarding infrastructure critical assets, hazard maps and data on risk with the city?	(-)
PWts05	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined, are they clearly identified on hazard maps and data on risk and is the city informed?	(-)
Infrastructure assets robustness		
PWts06	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PWts07	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PWts08	Water pump failures last year Average number of days that system pumps were out of order last year.	(Days)
PWts09	Water mains bursts last year Relative number of water mains bursts last year (No./system length (km) × 100 km).	(No./100 km)
PWts10	Water service connections bursts last year Number of water connections bursts last year (No./connections in the system × 1000 connections).	(No./1000 connections)
PWts11	Hydrant failures last year Average number of hydrant failures last year (No./hydrants in the system × 1000 hydrants).	(No./1000 hydrants)

Table A9. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Infrastructure assets robustness		
PWts12	Power failures last year Average number of days pumping stations were out of service due to power supply interruptions last year.	(Days)
PWts13	Water quality last year Percentage of performed laboratory analysis that were in accordance to legal or regulatory requirements last year.	(%)
PWts14	Level of failure of critical infrastructure asset last year Percentage of critical infrastructure asset out of order last year.	(%)
PWts15	Coverage of expenditure in infrastructure last year Ratio between expenditure with rehabilitation, operation and management of infrastructure and annual operating budget of last year.	(-)
PWts16	Time for restoration last year Maximum out-of-service period for all failures in infrastructure, including recovery time, last year (days).	(Days)
PWts17	Real water losses Volume of real physical water losses, through any leaks, damaged pipes or overflows (m^3/(km.day)).	(m^3/(km.day))
PWts18	Energy efficiency in pumping stations Average normalized energy consumption in PS - pumping stations = (Total energy consumption for pumping/sum (Water volume in PS i × Manometric pressure head i/100).	(kWh/m^3.100m)
PWts19	Pollution prevention Percentage of sludge from water treatment with appropriate final disposal.	(% appropriate sludge disposal)
AUTONOMOUS AND FLEXIBLE WATER INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PWts20	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the infrastructure and the following infrastructure, under the agreed scenarios:	(-)
PWts21	Infrastructure of other services dependency on water infrastructure The infrastructure of the following services is dependent on water infrastructure: a) Infrastructure of the wastewater service (…)	(-)
PWts22	Dependency on infrastructures of other services The infrastructure of the water service directly depends on the infrastructure of the following services: a) Infrastructure of the wastewater service (…)	(-)
PWts23	Level of dependency Percentage of customers affected by infrastructure dependent on other services.	(% customers affected)
Infrastructure assets autonomy		
PWts24	Autonomy from infrastructures of other services Percentage of infrastructure directly dependent on other services that have an autonomy solution managed by the water service.	(% infrastructure)
PWts25	Level of autonomy Percentage of customers covered by infrastructure dependent on other services that benefit from autonomy solutions (i.e., customers that benefit/customers affected).	(% customers covered)
PWts26	Autonomy activation How is infrastructure autonomy activated? Specify the time required to activate it, if possible.	(-)
PWts27	Autonomy period Weighted average of autonomy period (Ti) of each dependent infrastructure (i) (i.e., Sum (Ti × level of autonomy i)).	(Days)
PWts28	Water storage autonomy Days of water supply autonomy provided by supply and distribution storage tanks = water inflow (m^3/year)/(water storage volume (m^3) × 365)	(Days)
PWts29	Energy self-production Percentage of energy consumption coming from self-production.	(%)
Infrastructure assets redundancy		
PWts30	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
PWts31	Redundancy activation How is infrastructure redundancy activated? Specify the time required to activate it, if possible.	(-)
PWts32	Level of redundancy Percentage of customers covered by redundant infrastructure, i.e., with alternative infrastructure able to provide the service.	(% customers covered)

Table A9. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
WATER INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PWts33	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of the following solutions to improve city resilience: a) Soakaways and porous pavement (. . .)	(-)
PWts34	Greenhouse gas emission target Contribution to greenhouse gas emission reduction.	(-)
PWts35	Other contributions to city resilience The water infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PWts36	Level of exposure of critical infrastructure assets to the most probable scenario Identify the critical infrastructure asset for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PWts37	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure on infrastructure affected by climate change scenarios and annual operating budget of last year.	(%)
PWts38	Time for restoration for most probable scenario Maximum out-of-service period predicted for all failures in infrastructure, including recovery time, due to different hazards for climate change scenarios.	(Days)
Preparedness for climate change		
PWts39	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PWts40	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PWts41	Water pump failures in the last relevant event Number of days system pumps were out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PWts42	Water service mains failures in the last relevant event Number of mains failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./system length (km) × 100 km).	(No./100 km)
PWts43	Water service connection mains bursts in the last relevant event Number of water service connections mains bursts due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./connections in the system × 1000 connections).	(No./1000 connections)
PWts44	Hydrant bursts in the last relevant event Number of hydrant bursts due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./hydrants in the system × 1000 hydrants).	(No./1000 hydrants)
PWts45	Power failures in the last relevant event Number of days pumping stations were out of service by power supply interruptions due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PWts46	Water quality compliance in the last relevant event Percentage of laboratory analysis that were in accordance to legal or regulatory requirements due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PWts47	Level of failure of critical assets in the last relevant event Percentage of critical infrastructure asset out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PWts48	Coverage of expenditure in infrastructure in the last relevant event Ratio between expenditure on infrastructure affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario and annual operating budget of last year.	(%)
PWts49	Time for restoration in the last relevant event Maximum out-of-service period for all failures in infrastructure, including recovery time, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A10. Physical dimension for the wastewater infrastructure.

OBJECTIVE **Criterion** **PI**		**PI Unit**
SAFE WASTEWATER INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PWwt01	Wastewater infrastructure critical assets Are the critical infrastructure assets for service provision identified?	(-)
PWwt02	Component importance The identification of infrastructure critical assets is based in the following: a) Population served (...)	(-)
PWwt03	Wastewater infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PWwt04	Exchange of information Is there a regular exchange of information regarding infrastructure critical assets, hazard maps and data on risk with the city?	(-)
PWwt05	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined, are they clearly identified on hazard maps and data on risk and is the city informed?	(-)
Infrastructure assets robustness		
PWwt06	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PWwt07	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PWwt08	Wastewater pump failures last year Average number of days that system pumps were out of order last year.	(Days)
PWwt09	Wastewater sewer pipe collapses last year Relative number of collapses in wastewater sewers last year (No./system length (km) × 100 km).	(No./100 km)
PWwt10	Wastewater connection collapses last year Number of collapses in wastewater connections last year (No./connections in the system × 1000 connections).	(No./1000 connections)
PWwt11	Power failures last year Average number of days pumping stations were out of service due to power supply interruptions last year.	(Days)
PWwt12	Combined sewer overflow failures last year Average number of combined sewer overflows last year.	(CSO discharges/total CSO devices)
PWwt13	Wastewater quality last year Percentage of performed laboratory analysis that were in accordance to legal or regulatory requirements last year.	(%)
PWwt14	Level of failure of critical infrastructure assets last year Percentage of critical infrastructure asset out of order last year.	(%)
PWwt15	Coverage of expenditure in infrastructure last year Ratio between expenditure with rehabilitation, operation and management of infrastructure and annual operating budget of last year.	(-)

Table A10. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets robustness		
PWwt16	Time for restoration last year Maximum out-of-service period for all failures in infrastructure, including recovery time, last year.	(Days)
PWwt17	Real undue inflows into the wastewater infrastructure Volume of real physical undue inflows into the wastewater infrastructure, through joints, damaged pipes or wrong connections (m^3/(km.day)).	(m^3/(km.day))
PWwt18	Energy efficiency in pumping stations Average normalised energy consumption in PS – pumping stations = (Total energy consumption for pumping/sum (wastewater volume in PS i × Manometric pressure head i/100).	(kWh/m^3.100m)
PWwt19	Pollution prevention Percentage of sludge from wastewater treatment with appropriate final disposal.	(% appropriate sludge disposal)
AUTONOMOUS AND FLEXIBLE WASTEWATER INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PWwt20	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the infrastructure and the following infrastructure, under the agreed scenarios: a) Other infrastructure of the wastewater service (. . .)	(-)
PWwt21	Infrastructure of other services' dependency on wastewater infrastructure The infrastructure of the following services is dependent on wastewater infrastructure: a) Infrastructure of the water service (. . .)	(-)
PWwt22	Dependency on infrastructures of other services The infrastructure of the wastewater service directly depends on the infrastructure of the following services: a) Infrastructure of the water service (. . .)	(-)
PWwt23	Level of dependency Percentage of customers affected by infrastructure dependent on other services.	(% customers affected)
Infrastructure assets autonomy		
PWwt24	Autonomy from infrastructures of other services Percentage of infrastructure directly dependent on other services that have an autonomy solution managed by the wastewater service.	(% infrastructure)
PWwt25	Level of autonomy Percentage of customers covered by infrastructure dependent on other services that benefit from autonomy solutions (i.e., customers that benefit/customers affected).	(% customers covered)
PWwt26	Autonomy activation How is infrastructure autonomy activated? Specify the time required to activate it, if possible.	(-)
PWwt27	Autonomy period Weighted average of autonomy period (Ti) of each dependent infrastructure (i) (i.e., Sum (Ti × level of autonomy i)).	(Days)
PWwt28	Energy self-production Percentage of energy consumption coming from self-production.	(%)

Table A10. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets redundancy		
PWwt29	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
PWwt30	Redundancy activation How is infrastructure redundancy activated? Specify the time required to activate it, if possible.	(-)
PWwt31	Level of redundancy Percentage of customers covered by redundant infrastructure, i.e., with alternative infrastructure able to provide the service.	(% customers covered)
WASTEWATER INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PWwt32	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of the following solutions to improve city resilience: a) Soakaways and porous pavement (. . .)	(-)
PWwt33	Greenhouse gas emission target Contribution to greenhouse gas emission reduction.	(-)
PWwt34	Other contributions to city resilience The wastewater infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PWwt35	Level of exposure of critical infrastructure assets to the most probable scenario Identify the critical infrastructure asset for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PWwt36	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure with infrastructure affected by climate change scenarios and annual operating budget of last year.	(%)
PWwt37	Time for restoration for most probable scenario Maximum out-of-service period predicted for all failures in infrastructure, including recovery time, due to different hazards for climate change scenarios.	(Days)
Preparedness for climate change		
PWwt38	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PWwt39	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PWwt40	Wastewater pump failures in the last relevant event Number of days system pumps were out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PWwt41	Wastewater sewer pipe failures in the last relevant event Number of failures in wastewater sewers due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./system length (km) × 100 km).	(No./100km)
PWwt42	Wastewater connection failures in the last relevant event Number of failures in wastewater connections due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./connections in the system × 1000 connections).	(No./100km)
PWwt43	Combined sewer overflow failures in the last relevant event Number of combined sewer overflow failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(CSO discharges/total CSO devices)

Table A10. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Preparedness for recovery and build back		
PWwt44	Power failures in the last relevant event Number of days pumping stations were out of service by power supply interruptions due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PWwt45	Wastewater quality compliance in the last relevant event Percentage of laboratory analysis that were in accordance to legal or regulatory requirements due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PWwt46	Level of failure of critical assets in the last relevant event Percentage of critical infrastructure asset out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PWwt47	Coverage of expenditure in infrastructure in the last relevant event Ratio between expenditure on infrastructure affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario and annual operating budget of last year.	(%)
PWwt48	Time for restoration in the last relevant event Maximum out-of-service period for all failures in infrastructure, including recovery time, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A11. Physical dimension for the stormwater infrastructure.

OBJECTIVE **Criterion** **PI**		**PI Unit**
SAFE STORMWATER INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PSwt01	Stormwater infrastructure critical assets Are the critical infrastructure assets for service provision identified?	(-)
PSwt02	Component importance The identification of infrastructure critical assets is based in the following: a) Population served (. . .)	(-)
PSwt03	Stormwater infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PSwt04	Exchange of information Is there a regular exchange of information regarding infrastructure critical assets, hazard maps and data on risk with the city?	(-)
PSwt05	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined, are they clearly identified on hazard maps and data on risk and is the city informed?	(-)
Infrastructure assets robustness		
PSwt06	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PSwt07	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PSwt08	Stormwater pump failures last year Average number of days that system pumps were out of order last year.	(Days)
PSwt09	Stormwater sewer pipe collapses last year Relative number of pipe collapses last year (No./system length (km) × 100 km).	(No./100 km)
PSwt10	Stormwater connection collapses last year Number of collapses in stormwater connections last year (No./connections in the system × 1000 connections).	(No./1000 connections)

Table A11. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets robustness		
PSwt11	Inlet failures last year Average number of inlet failures last year (No./inlets in the system × 1000 inlets).	(No./1000 inlets)
PSwt12	Power failures last year Average number of days pumping stations were out of service due to power supply interruptions last year.	(Days)
PSwt13	Stormwater quality last year Percentage of performed laboratory analysis that were in accordance to legal or regulatory requirements last year.	(%)
PSwt14	Level of failure of critical infrastructure assets last year Percentage of critical infrastructure asset out of order last year.	(%)
PSwt15	Coverage of expenditure in infrastructure last year Ratio between expenditure with rehabilitation, operation and management of infrastructure and annual operating budget of last year.	(-)
PSwt16	Time for restoration last year Maximum out-of-service period for all failures in infrastructure, including recovery time, last year.	(Days)
Infrastructure assets robustness		
PSwt17	Real undue inflows into the stormwater infrastructure Volume of real physical undue inflows into the stormwater infrastructure (e.g., soil, wastewater, industrial, saline, water supply inflows), through joints, damaged pipes or wrong connections (m^3/(km.day)).	(m^3/(km.day))
PSwt18	Energy efficiency in pumping stations Average normalized energy consumption in PS - pumping stations = (Total energy consumption for pumping/sum (stormwater volume in PS i × Manometric pressure head i/100).	(-)
PSwt19	Pollution prevention Percentage of sludge from stormwater treatment with appropriate final disposal.	(% appropriate sludge disposal)
AUTONOMOUS AND FLEXIBLE STORMWATER INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PSwt20	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the infrastructure and the following infrastructure, under the agreed scenarios: a) Other infrastructure of the stormwater service (. . .)	(-)
PSwt21	Infrastructure of other services' dependency on stormwater infrastructure The infrastructure of the following services is dependent on stormwater infrastructure: a) Infrastructure of the water service (. . .)	(-)
PSwt22	Dependency on infrastructures of other services The infrastructure of the stormwater service directly depends on the infrastructure of the following services: a) Infrastructure of the water service (. . .)	(-)
PSwt23	Level of dependency Percentage of customers affected by infrastructure dependent on other services.	(% customers affected)
Infrastructure assets autonomy		
PSwt24	Autonomy from infrastructures of other services Percentage of infrastructure directly dependent on other services that have an autonomy solution managed by the stormwater service.	(% infrastructure)
PSwt25	Level of autonomy Percentage of customers covered by infrastructure dependent on other services that benefit from autonomy solutions (i.e., customers that benefit/customers affected).	(% customers covered)

Table A11. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets autonomy		
PSwt26	Autonomy activation How is infrastructure autonomy activated? Specify the time required to activate it, if possible.	(-)
PSwt27	Autonomy period Weighted average of autonomy period (Ti) of each dependent infrastructure (i) (i.e., Sum (Ti × level of autonomy i)).	(Days)
PSwt28	Capacity for zero floods Based on the historical data, estimative of the maximum return period without city-wide flood ensured by the existing stormwater infrastructure.	(Years)
PSwt29	Energy self-production Percentage of energy consumption coming from self-production.	(%)
Infrastructure assets redundancy		
PSwt30	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
PSwt31	Redundancy activation How is infrastructure redundancy activated? Specify the time required to activate it, if possible.	(-)
STORMWATER INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PSwt32	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of the following solutions to improve city resilience: a) Soakaways and porous pavement (. . .)	(-)
PSwt33	Greenhouse gas emission target Contribution to greenhouse gas emission reduction.	(-)
PSwt34	Other contributions to city resilience The stormwater infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PSwt35	Level of exposure of critical infrastructure assets to the most probable scenario Identify the critical infrastructure asset for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PSwt36	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure with infrastructure affected by climate change scenarios and annual operating budget of last year.	(%)
PSwt37	Time for restoration for most probable scenario Maximum out-of-service period predicted for all failures in infrastructure, including recovery time, due to different hazards for climate change scenarios.	(Days)
Preparedness for climate change		
PSwt38	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PSwt39	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PSwt40	Stormwater pump failures in the last relevant event Number of days system pumps were out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PSwt41	Stormwater sewer pipe failures in the last relevant event Number of failures in stormwater sewers due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./system length (km) × 100 km).	(No./100 km)
PSwt42	Stormwater connection failures in the last relevant event Number of failures in stormwater connections due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./connections in the system × 1000 connections).	(No./1000 connections)

Table A11. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Preparedness for recovery and build back		
PSwt43	Inlets failures in the last relevant event Number of inlets failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario (No./inlets in the system × 1000 inlets).	(No./1000 inlets)
PSwt44	Power failures in the last relevant event Number of days pumping stations were out of service by power supply interruptions due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PSwt45	Stormwater quality compliance in the last relevant event Percentage of laboratory analysis that were in accordance to legal or regulatory requirements due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PSwt46	Level of failure of critical assets in the last relevant event Percentage of critical infrastructure asset out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PSwt47	Coverage of expenditure in infrastructure in the last relevant event Ratio between expenditure on infrastructure affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario and annual operating budget of last year.	(%)
PSwt48	Time for restoration in the last relevant event Maximum out-of-service period for all failures in infrastructure, including recovery time, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A12. Physical dimension for the waste infrastructure.

OBJECTIVE **Criterion** **PI**		**PI Unit**
SAFE WASTE INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PSlw01	Solid waste infrastructure critical assets Are the critical infrastructure assets for service provision identified?	(-)
PSlw02	Component importance The identification of infrastructure critical assets is based in the following: a) Population served (. . .)	(-)
PSlw03	Solid waste infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PSlw04	Exchange of information Is there a regular exchange of information regarding infrastructure critical assets, hazard maps and data on risk with the city?	(-)
PSlw05	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined, are they clearly identified on hazard maps and data on risk and is the city informed?	(-)

Table A12. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets robustness		
PSlw06	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PSlw07	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PSlw08	Waste collection infrastructure components failures last year Average number of days with collection infrastructure components out of service last year.	(Days)
PSlw09	Waste management service facilities unavailable last year Relative number of waste management facilities unavailable for longer than 4 days, last year (facilities unavailable /total number of facilities).	(% facilities)
PSlw10	Waste management fleet failures last year Average number of days that at least 10% of the waste management fleet was out of service last year.	(-)
PSlw11	Waste containers dumped or displaced last year Relative number of waste containers dumped or displaced last year (number affected/total number of containers).	(% containers)
PSlw12	Power failures interrupting service last year Average number of days waste management were out of service due to power supply interruptions last year.	(Days)
PSlw13	Laboratory analysis compliance Percentage of laboratory analysis performed in disposal site that were in accordance to legal or regulatory requirements last year.	(%)
PSlw14	Level of failure of critical infrastructure assets last year Percentage of critical infrastructure asset out of order last year.	(%)
PSlw15	Coverage of expenditure in infrastructure last year Ratio between expenditure with rehabilitation, operation and management of infrastructure and annual operating budget of last year.	(-)
PSlw16	Time for restoration last year Maximum out-of-service period for all failures in infrastructure, including recovery time, last year.	(Days)
PSlw17	Pollution prevention Percentage of leachate from solid waste treatment with appropriate final disposal.	(% appropriate leachate disposal)
AUTONOMOUS AND FLEXIBLE WASTE INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PSlw18	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the infrastructure and the following infrastructure, under the agreed scenarios: a) Other infrastructure of the solid waste service (…)	(-)
PSlw19	Infrastructure of other services' dependency on solid waste infrastructure The infrastructure of the following services is dependent on waste infrastructure: a) Infrastructure of the water service (…)	(-)
PSlw20	Dependency on infrastructures of other services The infrastructure of the waste service directly depends on the infrastructure of the following services: a) Infrastructure of the water service (…)	(-)
PSlw21	Level of dependency Percentage of customers affected by infrastructure dependent on other services.	(% customers affected)

Table A12. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Infrastructure assets autonomy		
PSlw22	Autonomy from infrastructures of other services Percentage of infrastructure directly dependent on other services that have an autonomy solution managed by the solid waste service.	(% infrastructure)
PSlw23	Level of autonomy Percentage of customers covered by infrastructure dependent on other services that benefit from autonomy solutions (i.e., customers that benefit/customers affected).	(% customers covered)
PSlw24	Autonomy activation How is infrastructure autonomy activated? Specify the time required to activate it, if possible.	(-)
PSlw25	Autonomy period Weighted average of autonomy period (Ti) of each dependent infrastructure (i) (i.e., Sum (Ti × level of autonomy i)).	(Days)
PSlw26	Waste storage autonomy Days of waste storage autonomy provided by containers and transfer locations.	(Days)
PSlw27	Energy self-production Percentage of energy consumption coming from self-production.	(%)
Infrastructure assets redundancy		
PSlw28	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
PSlw29	Redundancy activation How is infrastructure redundancy activated? Specify the time required to activate it, if possible.	(-)
PSlw30	Level of redundancy Percentage of customers covered by redundant infrastructure, i.e., with alternative infrastructure able to provide the service.	(% customers covered)
WASTE INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PSlw31	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of the following solutions to improve city resilience: a) Soakaways and porous pavement (. . .)	(-)
PSlw32	Recovered material from waste treatment % of recovered material from treatment per year (including composting, recycling and direct recovery).	(% recovered material)
PSlw33	Greenhouse gas emission target Contribution to greenhouse gas emission reduction.	(-)
PSlw34	Other contributions to city resilience The solid waste infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PSlw35	Level of exposure of critical infrastructure assets to the most probable scenario Identify the critical infrastructure asset for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PSlw36	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure with infrastructure affected by climate change scenarios and annual operating budget of last year.	(%)
PSlw37	Time for restoration for most probable scenario Maximum out-of-service period predicted for all failures in infrastructure, including recovery time, due to different hazards for climate change scenarios.	(Days)

Table A12. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Preparedness for climate change		
PSlw38	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PSlw39	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PSlw40	Waste collection infrastructure components failures last relevant event Number of days waste collection infrastructure components were out of service due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PSlw41	Waste management service facilities unavailable in the last relevant event Number of waste management service facilities unavailable in the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% facilities)
PSlw42	Waste management fleet failures in the last relevant event Number of waste management fleet failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
PSlw43	Waste containers dumped or displaced in the last relevant event Number of waste containers dumped or displaced due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(% containers)
PSlw44	Power failures in the last relevant event Number of days waste management facilities were out of service by power supply interruptions due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PSlw45	Laboratory analysis compliance in the last relevant event Percentage of laboratory analysis performed in disposal site that were in accordance to legal or regulatory requirements in the last relevant event.	(%)
PSlw46	Level of failure of critical assets in the last relevant event Percentage of critical infrastructure asset out of order due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PSlw47	Coverage of expenditure in infrastructure in the last relevant event Ratio between expenditure on infrastructure affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario and annual operating budget of last year.	(%)
PSlw48	Time for restoration in the last relevant event Maximum out-of-service period for all failures in infrastructure, including recovery time, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A13. Physical dimension for the energy infrastructure.

OBJECTIVE **Criterion** **PI**		**PI Unit**
SAFE ENERGY INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PEne01	Energy infrastructure critical assets Are the critical infrastructure assets for service provision identified?	(-)
PEne02	Component importance The identification of infrastructure critical assets is based in the following:	(-)
PEne03	Energy infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PEne04	Exchange of information Is there a regular exchange of information regarding infrastructure critical assets, hazard maps and data on risk with the city?	(-)
PEne05	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined, are they clearly identified on hazard maps and data on risk and is the city informed?	(-)
Infrastructure assets robustness		
PEne06	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PEne07	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PEne08	Power station failure last year Average number of days that power stations were out of service due to infrastructure problems last year.	(Days)
PEne09	Power substation failure last year Average number of days that power substations were out of service due to infrastructure problems last year.	(Days)
PEne10	Power distribution network failures last year Number of failures in the distribution network last year.	(-)
PEne11	Local power installations failures last year Number of sectional and transformation power stations and public lighting installations failures last year.	(-)
PEne12	Level of failure of critical infrastructure assets last year Percentage of critical infrastructure assets out of order by failure last year.	(%)
PEne13	Coverage of expenditure in infrastructure last year Ratio between expenditure with rehabilitation, operation and management of infrastructure and annual operating budget of last year.	(-)
PEne14	Time for restoration last year Maximum out-of-service period for all failures in infrastructure, including recovery time, last year.	(Days)
PEne15	Use of cooling waters Water use per year for cooling power stations.	(l/kWh)
AUTONOMOUS AND FLEXIBLE ENERGY INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PEne16	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the infrastructure and the following infrastructure, under the agreed scenarios: a) Other infrastructure of the energy service (…)	(-)
PEne17	Infrastructure of other services' dependency on energy infrastructure The infrastructure of the following services is dependent on energy infrastructure: a) Infrastructure of the wastewater service (…)	(-)
PEne18	Dependency on infrastructures of other services The infrastructure of the energy service directly depends on the infrastructure of the following services: a) Infrastructure of the wastewater service (…)	(-)
PEne19	Level of dependency Percentage of customers affected by infrastructure dependent on other services.	(% customers affected)

Table A13. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets autonomy		
PEne20	Autonomy from infrastructures of other services Percentage of infrastructure directly dependent on other services that have an autonomy solution managed by the energy service.	(% infrastructure)
PEne21	Level of autonomy Percentage of customers covered by infrastructure dependent on other services that benefit from autonomy solutions (i.e., customers that benefit/customers affected).	(% customers covered)
PEne22	Autonomy activation How is infrastructure autonomy activated? Specify the time required to activate it, if possible.	(-)
PEne23	Autonomy period Weighted average of autonomy period (Ti) of each dependent infrastructure (i) (i.e., Sum (Ti × level of autonomy i)).	(Days)
Infrastructure assets redundancy		
PEne24	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
PEne25	Redundancy activation How is infrastructure redundancy activated? Specify the time required to activate it, if possible.	(-)
PEne26	Level of redundancy Percentage of customers covered by redundant infrastructure, i.e., with alternative infrastructure able to provide the service.	(% customers covered)
ENERGY INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PEne27	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of the following solutions to improve city resilience: a) Soakaways and porous pavement (. . .)	(-)
PEne28	Greenhouse gas emission target Contribution to greenhouse gas emission reduction.	(-)
PEne29	Other contributions to city resilience The energy infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PEne30	Level of exposure of critical infrastructure assets to the most probable scenario Identify the critical infrastructure asset for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PEne31	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure with infrastructure affected by climate change scenarios and annual operating budget of last year.	(%)
PEne32	Time for restoration for most probable scenario Maximum out-of-service period predicted for all failures in infrastructure, including recovery time, due to different hazards for climate change scenarios.	(Days)

Table A13. *Cont.*

OBJECTIVE Criterion PI		PI Unit
Preparedness for climate change		
PEne33	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PEne34	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PEne35	Power stations failure in the last relevant event Average number of days that power stations were out of service due to infrastructure problems due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PEne36	Power substation failure in the last relevant event Average number of days that power substations were out of service due to infrastructure problems due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)
PEne37	Power distribution network failures in the last relevant event Number of failures in the distribution network due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
PEne38	Local power installation failures in the last relevant event Number of sectional and transformation power stations and public lighting installation failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
PEne39	Level of failure of critical assets in the last relevant event Percentage of critical infrastructure asset out of order by failure due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(%)
PEne40	Coverage of expenditure in infrastructure in the last relevant event Ratio between expenditure on infrastructure affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario and annual operating budget of last year.	(-)
PEne41	Time for restoration in the last relevant event Maximum out-of-service period for all failures in infrastructure, including recovery time, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Days)

Table A14. Physical dimension for the mobility infrastructure.

OBJECTIVE Criterion PI		PI Unit
SAFE MOBILITY INFRASTRUCTURE		
Infrastructure assets criticality and protection		
PMob01	Mobility infrastructure critical assets Are the critical infrastructure assets for mobility identified?	(-)
PMob02	Component importance for city mobility The identification of infrastructure critical assets for city mobility is based in the following: a) Population served (. . .)	(-)
PMob03	Mobility infrastructure critical assets mapping, review and update Are the infrastructure critical assets identified on hazard maps and included in data on risk?	(-)
PMob04	Protective buffers mapping and information to the city Have protective buffers to safeguard infrastructure assets been defined and are they clearly identified on hazard maps and data on risk?	(-)

Table A14. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets robustness		
PMob05	Codes and standards for infrastructure Do codes or standards for infrastructure design and construction exist and are these implemented?	(-)
PMob06	Maintenance of infrastructure Is infrastructure maintained on a regular basis (according to a preventive maintenance plan), resources for corrective maintenance are assured and all maintenance information is continuously registered?	(-)
PMob07	Road and rail routes failures last year Critical routes were out of order for less than 2 h on average last year, for these infrastructures: a) Road based (. . .)	(-)
PMob08	Transport interfaces failures last year Average number of hours that critical transport interfaces were out of order due to infrastructural failures last year.	(Hours)
PMob09	Power-related failures in road and rail routes last year Critical routes were out of order for less than 2 h on average, due to power-related failures, last year.	(-)
PMob10	Power-related failures in transport interfaces last year Average number of hours that critical transport interfaces were out of order due to power-related failures, last year.	(Hours)
PMob11	Flooding-related failures in road and rail routes last year Critical routes were out of order for less than 2 h on average, due to flooding, last year.	(-)
PMob12	Flooding-related failures in transport interfaces last year Average number of hours that critical transport interfaces were out of order due to flooding-related failures on average, last year.	(Hours)
PMob13	Coverage of expenditure in infrastructure last year Ratio of expenditure with rehabilitation, operation and management of infrastructure (routes and interfaces) and annual operating budget of last year between 0.9 and 1.0 or between 1.1 and 1.2, for these infrastructures: a) Road based (. . .)	(-)
PMob14	Time for restoration last year Mobility critical infrastructure (routes and interfaces) with a maximum out-of-service period for all failures in infrastructure, including recovery time, less than or equal to 7 h last year, for these infrastructures: a) Road based (. . .)	(-)
PMob15	Clean fuel public transport Existence of alternative clean fuel public transport in the city.	(-)
AUTONOMOUS AND FLEXIBLE MOBILITY INFRASTRUCTURE		
Infrastructure assets importance to and dependency on other services		
PMob16	Cascading impacts There is knowledge concerning potentially cascading failures between the components of the mobility infrastructure (road, train, air and water-based transport that applies) and the following infrastructure, under the agreed scenarios: a) Full knowledge between the components of the mobility infrastructure (. . .)	(-)
PMob17	Infrastructure of other services' dependency on mobility infrastructure The infrastructure of the following services is dependent on mobility infrastructure: a) Infrastructure of the water service (. . .)	(-)
PMob18	Dependency on infrastructures of other services The infrastructure of the mobility service directly depends on the infrastructure of the following services: a) Infrastructure of the water service.	(-)

Table A14. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Infrastructure assets autonomy and redundancy		
PMob19	Energy self-production Percentage of energy consumption coming from self-production.	(%)
PMob20	Redundancy Is there an understanding of infrastructure redundancy, clearly identified on hazard maps and data on risk?	(-)
MOBILITY INFRASTRUCTURE PREPAREDNESS		
Contribution to city resilience		
PMob21	Use of design solutions to improve city resilience The design of the infrastructure incorporates the use of solutions to improve city resilience: a) Renewable energy generation (. . .)	(-)
PMob22	Greenhouse gas emission target There is a prediction of GHG emissions reduction, aiming at the targets defined at the strategic planning level, from the following components of assets: a) Infrastructure operation (. . .)	(-)
PMob23	Other contributions to city resilience The mobility infrastructure and related services provide other contributions to city resilience in emergency situation, such as: a) Shelter (. . .)	(-)
Infrastructure assets exposure to climate change		
PMob24	Level of exposure of mobility infrastructure to the most probable scenario Identify the critical assets for which less than 10% is exposed to different hazards for climate change scenarios.	(-)
PMob25	Coverage of expenditure in infrastructure for most probable scenario Ratio between predicted expenditure with infrastructure (routes and interfaces) affected by climate change scenarios and annual operating budget of last year between 0.9 and 1.0 or 1.1 and 1.2, for these infrastructures: a) Road based (. . .)	(-)
PMob26	Time for restoration for most probable scenario Transport networks with maximum out-of-service period for all failures in infrastructure (routes and interfaces), including recovery time, for less than 7 h, due to different hazards for climate change scenarios, for these infrastructures: a) Road based (. . .)	(-)
Preparedness for climate change		
PMob27	Implemented infrastructural measures to address CC mitigation and adaptation What type of measures were implemented in infrastructure design to address climate change mitigation and adaptation?	(-)
PMob28	Planned infrastructural measures to address CC mitigation and adaptation What type of measures are being planned in infrastructure design to address climate change mitigation and adaptation?	(-)
Preparedness for recovery and build back		
PMob29	Road and rail routes failures in the last relevant event Critical routes were out of order for less than 2 h on average due to the last climate-related event, with similar or harsher climate variables than the most probable scenario, for these infrastructures: a) Road based (. . .)	(-)
PMob30	Transport interfaces failures in the last relevant event Average number of hours that critical transport interfaces were out of order due to infrastructural failures due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Hours)
PMob31	Power-related failures in road and rail routes in the last relevant event Critical routes were out of order for less than 2 h on average, by power-related failures, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
PMob32	Power-related failures in transport interfaces in the last relevant event Critical routes were out of order for less than 2 h due to flooding on average, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(-)
PMob33	Flooding-related failures in road and rail routes in the last relevant event Average number of hours that critical transport interfaces were out of order due to flooding-related failures on average, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Hours)

Table A14. *Cont.*

OBJECTIVE **Criterion** **PI**		**PI Unit**
Preparedness for recovery and build back		
PMob34	Flooding-related failures in transport interfaces in the last relevant event Average number of hours that critical transport interfaces were out of order due to power-related failures, due to the last climate-related event, with similar or harsher climate variables than the most probable scenario.	(Hours)
PMob35	Coverage of expenditure in infrastructure in the last relevant event Ratio of expenditure on rehabilitation, operation and management of infrastructure (routes and interfaces) affected by the last climate-related event, with similar or harsher climate variables than the most probable scenario, and annual operating budget of last year, is between 0.9 and 1.0 or 1.1 and 1.2, for these infrastructures: a) Road based (. . .)	(-)
PMob36	Time for restoration in the last relevant event Mobility critical infrastructure (routes and interfaces) with a maximum out-of-service period for all failures in infrastructure, including recovery time, less than or equal to 7 h due to the last climate-related event, with similar or harsher climate variables than the most probable scenario, for these infrastructures: a) Road based (. . .)	(-)

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