

# Supporting urban adaptation to climate change: what role can resilience measurement tools play?

Sara Mehryar, Idan Sasson and Swenja Surminski

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# 1 Supporting Urban Adaptation: What Role Can Resilience Measurement Tools Play?

2 Sara Mehryar, Idan Sasson, Swenja Surminski

3 **Summary:** Cities are emerging as leading forces for climate change adaptation and resilience due to their  
4 financial, technological, and human capacities. Many approaches and tools have been developed and used  
5 over the last decades to measure climate resilience in cities and identify areas that need further  
6 intervention. In this study, we explore how and to what extent such tools can be or have been utilized by  
7 city-level actors to support their decision-making process for building climate resilience. To do this, we  
8 applied a document analysis of 27 tools developed for measuring urban climate resilience and  
9 supplemented it with 12 semi-structured interviews with local experts involved in implementation of  
10 these tools across the world. Our analysis shows that only 10 of these tools are designed to support  
11 implementing resilience actions while the rest mainly focus on sharing knowledge and raising awareness.  
12 We also observed a prevailing focus on evaluating coping capacities (as opposed to adaptive and  
13 transformative capacities) of cities against climate risks in such tools, which tends to trigger short-term  
14 solutions rather than long-term transformational adaptation strategies. Therefore, we argue that urban  
15 climate resilience measurement tools need to 1) support action implementation processes as much as  
16 assessing outcomes, and 2) consider the enabling environment for enhancing adaptive and transformative  
17 capacities as much as coping capacities of cities. Finally, we explore challenges and opportunities of  
18 resilience measurement practices for decision-making drawn from end-users' insights.

19

## 20 1. Introduction

21 Urban areas are crucial in supporting the broader response to climate risks. This is because they serve as  
22 centres of economic activity, technology, and innovation. However, urban centres are often also exposed  
23 to a wide array of climate risks including sea-level rise, heat waves, various types of flooding,  
24 windstorms, and landslides. Such climate risks are increasing not only from increased frequency and  
25 severity of weather extremes due to climate change, but also because of the massive rates of urbanization  
26 that our current economic system is perpetuating. Hanson et al. (2011) estimate that by the 2070s, total  
27 population of the port cities exposed to coastal flood events could grow more than threefold, and a recent  
28 study by (Wolff et al., 2020) estimate that by 2100 the total urban exposure of 10 European countries to  
29 coastal flood risks could increase up to 104% due to the combined effects of sea-level rise, population  
30 growth, and urbanization. These pose real dangers to urban residents, their livelihoods, and assets, as well  
31 as businesses operating in the cities and critical infrastructure serving them. Furthermore, many of these  
32 climate risks and associated shocks and stresses overlap, compounding the challenges decision-makers  
33 face. Such multifaceted risks put further pressure on those trying to manage these risks and those living,  
34 working and financially invested in urban areas.

35 As cities continue to grow and struggle with the uncertainties and challenges of climate change, “urban  
36 climate resilience” has received traction as a holistic framework for managing risk and planning effective  
37 solutions by urban planners and policy-makers in cities (Marschütz et al., 2020; Bellinson and Chu,  
38 2019; Meerow et al., 2016; Leichenko, 2011). In this paper we define ‘climate resilience’<sup>1</sup> as capacity of  
39 people and systems to sustain and improve their livelihood and development opportunities and wellbeing  
40 despite environmental, economic, social, and political disturbances caused by climate change (Tanner et  
41 al., 2015; Clare et al., 2017; Tyler and Moench, 2012; Tyler et al., 2016). This builds on the literature  
42 and concepts of disaster resilience that have emerged from the original ecological concept of resilience,

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<sup>1</sup> Hereafter we use ‘climate resilience’ and ‘resilience’ interchangeably.

1 first introduced by Holling (1973). Although resilience as a concept is not new, its meaning and  
2 application for decision-making is often unclear and various definitions and frameworks have been  
3 developed to transfer resilience from a concept to something tangible and applicable to decision-making  
4 and planning in the climate and disaster risks space. Among these are definitions that consider the multi-  
5 dimensional nature of resilience: determinants of resilience include a combination of social, financial,  
6 physical, human and natural factors that interact with one another to determine how an entity (e.g.  
7 household, community, city, country, etc.) responds to shocks and stresses (Keating et al., 2017b;  
8 Keating et al., 2017a; Campbell et al., 2019). Moreover, it has been widely discussed that resilience is not  
9 binary—i.e. it exist or it doesn't—(Southwick et al., 2014) but that instead it may be present to different  
10 degrees across multiple domains and risks. For example, a city that is known to be resilient to flood risks  
11 may not be resilient to urban heat issues. In addition, resilience is not fixed but a continually changing  
12 process that depends on developments in cities and changes of risks—defined as evolutionary resilience  
13 by Davoudi et al. (2012). Therefore, there is a general consensus that resilience should not be seen as a  
14 state or outcome but a dynamic process and set of conditions embodied within a system (Norris et al.,  
15 2008; Mitchell and Harris, 2012). In fact, Carpenter et al. (2001) described resilience as a measurable  
16 quantity that can be assessed only after specifying 'resilience of what to what and for whom'. To address  
17 such complex, dynamic and context-specific definitions of resilience, "resilience measurement" concepts,  
18 frameworks and tools have been developed to assist our understanding of 'holistic' resilience in each  
19 specific context.

20 Over the last decade a range of frameworks, tools and concepts have been developed under the umbrella  
21 of 'measuring urban climate resilience'. Many international initiatives and humanitarian organizations  
22 such as the World Resources Institute, ARUP, UN office for Disaster Risk Reduction, and Asian Cities  
23 Climate Resilience Network, together with national and regional governments have collaborated with  
24 cities across the world and developed versions of resilience indicators to measure resilience of  
25 households, communities, cities, regions, or countries against extreme weather events and wider physical  
26 impacts of climate change. Some of these tools are location and hazard-specific while others have an all-  
27 hazards, multi-community and multi-cultural approach for measuring resilience (Ostadtaghizadeh et al.,  
28 2015).

29 Many review studies have consequently been developed over the last decade to analyse the common  
30 conceptual and methodological hurdles and opportunities of such tools (Sharifi, 2016; Asadzadeh et al.,  
31 2017; Saja et al., 2019; Cai et al., 2018; Brown et al., 2018). Despite all the effort on analysing and  
32 improving the methodological aspects of such tools, what is less clear is how resilience measurement  
33 tools can actually support decision making for enhancing urban climate resilience. In other words: to what  
34 extent can resilience measurement tools be or have been utilized by city-level actors to support their  
35 decision-making process for building climate resilience?

36 In this study, we examine:

- 37 • RQ1: If and how the suite of resilience measurement tools supports *decision-making* toward  
38 building climate resilience in cities (Content and implementation process of tools).
- 39 • RQ2: How the use of such tools has influenced resilience *actions* in cities and what the challenges  
40 and opportunities of building resilience have been (End-users experiences and insights).

41  
42 To answer the first question, we systematically analyse 27 urban resilience measurement tools using the  
43 decision-making cycle and resilience capacities frameworks. To answer the second question, we assess  
44 results from 12 key-informant interviews with experts who were involved in implementation of four of  
45 the most widely applied tools across the world.

1 It should be noted that this study does not set out to evaluate the methodological and underlying  
2 conceptualization of resilience measurement tools, but it is specifically focused on supporting resilience  
3 decision-making and actions in response to urban climate risks. There are several papers providing meta-  
4 analysis of tools on the methodological and conceptual elements that readers can refer to—see studies  
5 cited above.

6  
7 Section 2 provides conceptual frameworks we adopted and used for analysing the content and  
8 implementation process of tools. Sections 3 explains the data collection and analysis methods. Section 4  
9 presents the results of our analysis, and finally, section 5 discusses findings and offers concluding  
10 thoughts.

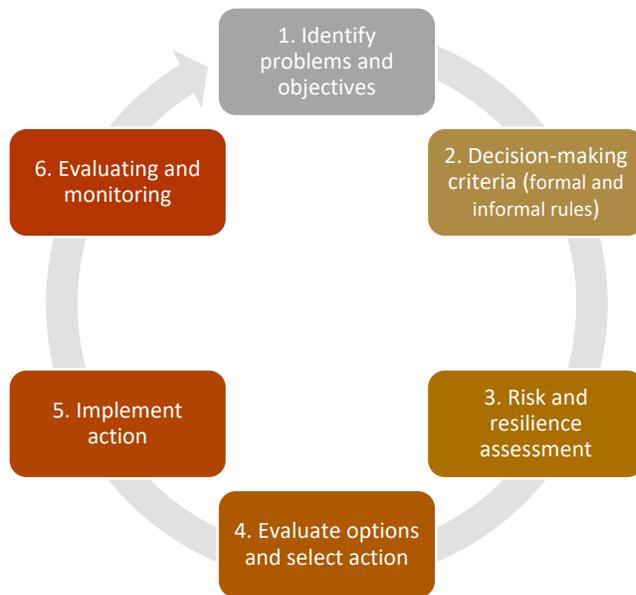
## 11 **2. Conceptual frameworks**

13 To analyse if and how resilience measurement tools are supporting decision-making toward building  
14 resilience (RQ1) we rely on the literatures on decision-making and resilience theories and employ two  
15 conceptual frameworks as described below.

### 16 **2.1. Decision cycle**

17 Decision theory literature frames the pathway from identifying problems to implementing actions as a  
18 decision cycle shown in figure 1. It starts with identifying the main problems and criteria that may  
19 constrain decision-making processes (i.e., formal and informal rules), and is followed by the ex-ante  
20 assessment of alternative actions, selecting and implementing actions, and finally ex-post evaluation and  
21 monitoring of actions. This is ideally an iterative process with internal feedback loops among different  
22 stages, thus, it does not always follow the circle steps in an orderly fashion. This decision cycle has been  
23 widely adopted and discussed in disaster and climate risk management studies (McDermott and  
24 Surminski, 2018; Mechler et al., 2019; IIASA & Zurich, 2015; Swart et al., 2021) yet not all its stages  
25 are commonly applied in practice. While there has been a great deal of effort in developing methods and  
26 providing data for the first three steps (particularly data on the level of probability and severity of future  
27 hazards, vulnerability, exposure, and resilience of communities) what often remains challenging is the  
28 implementation of actions, and ex-ante and ex-post evaluation and monitoring of measures i.e., stages 4  
29 and 6 (Surminski and Leck, 2017).

30



1

2 Figure 1. Different stages of the ‘decision cycle’ widely adopted for climate adaptation and disaster risk reduction  
 3 decision-making studies – adopted from McDermott and Surminski (2018), IIASA & Zurich (2015), and  
 4 CLIMATE-ADAPT Urban Adaptation Support Tool of the European Environment Agency, see [https://climate-](https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-0)  
 5 [adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-0](https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-0).

6 As Surminski and Leck (2017) explain, in the context of urban climate decision-making, stages 1-3 are  
 7 more focused on agenda-setting, planning, knowledge sharing and raising awareness, while stages 4-6 are  
 8 aimed at implementing solutions and delivering actions. Transitioning from agenda setting to  
 9 implementation is reported as the core of urban resilience discourse, where, after a period of evidence  
 10 collection and analysis, actors are facing the challenge of implementing solutions (Surminski and Leck,  
 11 2017). McDermott and Surminski (2018) argue that even in cities with great access to accurate data on  
 12 climate risk and resilience (stage 3), what often determines if and what action is taken is the normative  
 13 interpretation of this information by urban decision-makers and their political judgements. This has led to  
 14 growing interest in more innovating ways of supporting the implementation phase of the decision cycle  
 15 for climate resilience.

16

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## 2.2. Three elements of decision-making enabling urban climate resilience

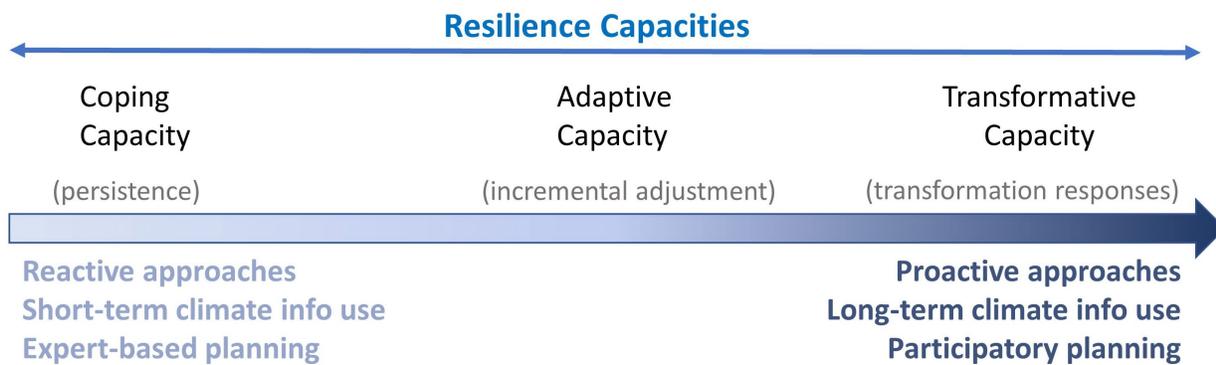
18 Resilience is traditionally defined in social-ecological systems as the ability to deal with the impacts of  
 19 adverse changes and shocks (Gunderson, 2000). This ability includes ‘shock absorbing and coping’, but  
 20 also ‘evolving and adapting’ or even ‘transforming’ (Walker et al., 2002; Folke et al., 2010). Making a  
 21 city climate-resilient, similarly, is increasingly recognized as developing plans, programs, and strategies  
 22 that improve the capacity of communities to cope with, adapt to, and transform in fact of potential threats  
 23 and changes (Khazai et al., 2015). Decision-making for urban climate resilience spans areas of local  
 24 government, including urban planning, disaster risk management, climate adaptation, and economic  
 25 development. Hence, decision-making in all these areas needs to include not only short-term coping  
 26 strategies that assist returning to the ‘pre-shock situation’, but also long-term adaptation and  
 27 transformation strategies that facilitate ‘adjusting to climate change impacts’, and ‘creating a new system’  
 28 when the existing system is untenable or undesirable (Engle et al., 2014). In the latter, “resilience”  
 29 practice might aim not to maintain the system’s current identity (in this case cities’ form, structure and  
 30 processes) but, rather, improve it (Orleans Reed et al., 2013). Resilience thinking has, however, been  
 31 challenged for promoting an incremental approach to coping and persistence that does not fully recognize  
 32 the need for change and transformation in the rapidly changing cities, and therefore, reinforce the status

1 quo and existing vulnerabilities (Keating and Hanger-Kopp, 2020). This is partially because the concept  
 2 of resilience has been largely adopted from the ecological and physical systems studies focusing on  
 3 recovering from disruption, bouncing back and robustness (Friend and Moench, 2013).

4 While investments in coping capacities is crucial in improving resilience to climate change, it is  
 5 manifestly inadequate to *only* invest of coping capacities; urban climate resilience strategies should, in  
 6 fact, address all three areas of resilience capacities. We draw on well-established research on adaptation  
 7 and transformational decision-making (see citations in following sub-sections) to unpack some of the  
 8 elements of decision-making that can foster adaptative and transformative capacities versus those that  
 9 perpetuate coping capacities in the context of climate change (figure 2).

10

11 Figure 2: Three elements of decision-making that trigger or hinder adaptation and transformation in the context of  
 12 climate change – adapted from Béné et al. (2014)



13

14

15 **Proactive approaches:** To increase adaptive and transformative capacities, cities need to take proactive  
 16 approaches in addressing climate risks, which foster forward thinking and innovative solutions (Quay,  
 17 2010; Park et al., 2012; Malekpour et al., 2015; Mehryar and Surminski, 2020). Proactive strategies  
 18 actively strive to minimise risks by reducing exposure and vulnerability to climate impacts in urban areas.  
 19 In other words, a proactive approach does not wait for external events to respond to, but instead  
 20 “anticipate opportunities for adaptation and transformation, and disrupt the system from within to bring  
 21 about large-scale changes” (Novalia and Malekpour, 2020). In the context of urban climate resilience,  
 22 proactive strategies are associated with ex-ante activities that are used to either reduce *existing* risks  
 23 (called *corrective risk reduction*) or avoid the development of new or increased risks in future (called  
 24 *prospective risk reduction*) (Mehryar and Surminski, 2021). For example, employing climate-smart urban  
 25 planning may enforce a land-use change in areas exposed to increasing weather extremes, in order to  
 26 avoid locating people and infrastructure in these areas and thereby increasing risks (i.e., prospective risk  
 27 reduction), while building flood walls and retrofitting of critical infrastructures help to reduce the existing  
 28 flood risks for assets and population already at risk (i.e., corrective risk reduction). On the contrary, a  
 29 purely reactive strategy would focus on increasing coping capacity to respond and recover from specific  
 30 crises. Whilst providing the response and recovery measures in the aftermath of catastrophic events is  
 31 important, prioritization of such short-term reactive over proactive measures can lead to accelerating the  
 32 “status quo” over the long run (Novalia and Malekpour, 2020).

33 **Long-term climate information use:** Recognizing and taking account of climate change impacts is an  
 34 important enabler of planning for adaptation and transformation. Long-term climate projections provide

1 useful information on climate and weather trends, and possible exposure to hazards in the future. Climate  
2 services provide science-based climate information and knowledge to support climate-smart decision-  
3 making at all levels of society (Vaughan and Dessai, 2014). A report published by LTS and DFID (2020)  
4 argues that access to and use of long-term climate information can support uptake of adaptive and  
5 transformative measures in accordance with the future climate variability, whereas relying on short-term  
6 climate information such as 1-14 day or seasonal weather forecasting can only support short-term  
7 preparation and coping measures. Advances in historical observation, data processing, and computer  
8 modelling over the last three decades have led to an expansion of available climate information and  
9 services, from seasonal weather forecasts to decadal and multi-decadal climate change projections (Soares  
10 et al., 2018). However, the provision, contextualization, and uptake of this information amongst urban  
11 climate-sensitive sectors (e.g., infrastructure, urban planning, health) is often reported to be inadequate or  
12 challenging (Lemos et al., 2012; Hewitt et al., 2017; Jones et al., 2017; Golding et al., 2017).

13 **Participatory planning:** Adaptation and transformation involve significant changes in thinking from the  
14 individual to the organizational level (Rickards et al., 2014). Participatory planning (i.e., based on  
15 involving various types of stakeholders in the process of analysing problems and designing,  
16 implementing, and evaluating solutions) facilitates social learning and enhances understanding of  
17 subsequent transformational changes. Participatory planning can also foster the multi-sectoral  
18 collaboration and collective decision-making required for adaptation and transformation (Fedele et al.,  
19 2019). The diversity of perspectives gathered in a participatory planning setting is generally recognized in  
20 the literature as an important aspect of learning and transformative capacity (Pelling et al., 2015; Broto et  
21 al., 2019).

22 Therefore, we argue that decision-making processes that include these three elements, i.e., proactive  
23 approach, climate information use, and participatory planning, are more likely to motivate building  
24 resilience (i.e., adaptation and transformation capacities as well as coping capacities) to growing urban  
25 climate risks. We acknowledge that building resilience is a complex process and there are multiple factors  
26 influencing decision-making for resilience. Here we do not discuss, for example, issues around  
27 availability and quality of data and judgement-based or normative decision-making which are also among  
28 decision-making elements that influence resilience building. Nevertheless, we argue that the three  
29 decision-making elements introduced in this section may not guarantee but lack of them hamper building  
30 or enhancing resilience, and particularly transformative capacities.

### 31 **3. Methods and data collection**

32 We identified and analysed 27 resilience measurement tools<sup>2</sup> developed for assessing climate resilience of  
33 cities across the world (see table 2). “Web of Science”, “Google Scholar” and “Google” were used to  
34 collect both scientific and non-scientific documents referring to any of these tools. A combination of  
35 “climate/hazard/disaster” AND “resilience” AND “measurement/assessment” AND  
36 “tool/toolkit/index/matrix/indicator” were used as search strings. This search also included hazard-  
37 specific tools (e.g., flood resilience measurement tools) so long as they have one of the  
38 climate/hazard/disaster words in their documents. Although not all hazard/disaster tools have been  
39 developed to particularly address ‘climate’ resilience, we still included them as they are generally being  
40 used to measure resilience to the acute shocks (e.g., flooding) and chronic stresses (e.g., drought) caused  
41 or developed by climate change. In addition, our data collection results were then sense checked with

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<sup>2</sup> We use the term “tool” to refer to all types of assessment schemes that include a set of indicators or parameters defined for measuring resilience and a methodology for collecting and/or analysing data. Different developers may use different terms such as tools, toolkit, index, scorecard, or framework.

1 experts from Mercy Corps, ISET-international and the Zurich Flood Resilience Alliance (who have  
 2 worked on the review and analysis of existing resilience measurement tools) to make sure a full list of  
 3 relevant tools were included. Following the aim of this study, we excluded tools that 1) have not been  
 4 applied in any *urban area*, or 2) have not been implemented beyond pilot study stage nor have a user  
 5 manual to support the application of the tool by local decision-makers.

6 Additionally, in-depth semi-structured interviews were conducted with 12 key informants who have been  
 7 involved in implementation of four of the most widely applied tools in over 100 cities, in total. The  
 8 selection of interviewees was done in a way to ensure cross-representation and recognition of geographic,  
 9 governance and socio-economic balance in the use and application of tools. In addition, as the aim of  
 10 interviews were to gather insights on the application of resilience measurement tools (in general) in  
 11 decision-making, the interviewees were selected among those who were involved in applying at least one  
 12 of the tools in many cities across the world. The overarching themes of the interview discussions were:

- 13 1- What were the main impacts of applying resilience measurement tools in cities you worked with?
- 14 2- If and how the results of tools have been used to support taking actions toward resilience?
- 15 3- What have been the most important barriers/challenges in implementing an intervention based on
- 16 the measurement results?

17 More information about the interviewees, tools they used, and cities/countries in which they applied the  
 18 tools can be seen in Supplementary 1.

19 **Content analysis criteria:** based on the two frameworks presented in section 2, we analysed to what  
 20 extent the 27 tools support 1) the 6 stages of the decision-making cycle, particularly those focused on  
 21 implementation (stages 4-6) in addition to awareness (stages 1-3), and 2) the three elements of decision-  
 22 making that foster adaptation and transformational actions, as set out in figure 2. To do the latter, we  
 23 applied the following analysis criteria.

24 Table 1: Criteria for analysing tools

Element of decision-making for climate resilience	Criteria for analysing tools
<b>Proactive approach</b>	<i>Corrective &amp; Prospective Risk reduction:</i> Are risk reduction measures/activities being recognized (measured) as well as the response/recovery measures/activities?
<b>Climate information use</b>	<i>Climate change indicator:</i> do the tools have any indicator/parameter/question on climate change and its impacts?
	<i>Climate info use in methodology:</i> are climate change predictions and scenarios being used in the process of measuring resilience?
<b>Participatory planning</b>	<i>Participatory planning indicator:</i> do the tools have any indicator on participatory approach in planning and decision-making?
	<i>Participatory approach in methodology:</i> is participatory approach being used in the process of measuring resilience?

25

1 *Corrective & Prospective Risk reduction*: To assess **proactive approaches**, we assessed whether the 27  
 2 tools include indicators to evaluate *prospective* and *corrective risk reduction* strategies (i.e., proactive  
 3 strategies to avoid or reduce future risks) in cities in addition to response and recovery (i.e., reactive  
 4 strategies used for coping with future risks).

5 *Climate change indicator & climate information use in methodology*: to assess **climate information use**,  
 6 we analysed if and how the 27 tools 1) include any indicator/parameter/question to evaluate level of  
 7 climate change awareness and climate information use by local stakeholders, and 2) use climate scenarios  
 8 and predictions as a part of their methodology to assess resilience of communities against future risks.

9 *Participatory planning indicator & participatory approach in methodology*: to assess **participatory**  
 10 **planning**, we analysed if and how the 27 tools 1) include any indicator to measure community  
 11 participation in the process of decision-making for resilience building in cities, and 2) take a participatory  
 12 approach in their methodology to collect and analyse data for measuring urban climate resilience.

#### 13 4. Results

14 Among the 27 tools identified, 11 tools were found to be specifically developed for urban areas, while the  
 15 remaining 16 tools are applicable in both urban and non-urban areas. These 27 tools have been developed  
 16 by academia (n=13), international organizations or multi-organization collaborations (n=10), and national  
 17 governments and consultancies (n=4). 16 of these tools were specifically initiated by (i.e., developed on  
 18 the request of) national governments (e.g., the US EPA) or international philanthropic organizations (e.g.,  
 19 the Rockefeller Foundation and Z Zurich Foundation). Interestingly, only 3 tools are specifically designed  
 20 to measure climate resilience (MONARES and EURCC), or climate and disaster resilience (CDRI<sup>1</sup>), and  
 21 others measure resilience to disasters and hazards that are impacts of climate change. Among the tools  
 22 analysed, 8 tools measure resilience to *climate-related hazards* (including both acute shocks and long-  
 23 term stresses), 16 tools measure resilience to *all hazards* including climate and non-climate-related  
 24 hazards (e.g., earthquake, volcano, etc.), and 3 tools measure resilience to single hazards, i.e., all acute  
 25 shocks: flooding, and coastal hazards such as tsunamis, storms, and shoreline erosion. Although most of  
 26 the tools have been developed and introduced as universally applicable, only 7 of them have been so far  
 27 implemented and tested across different continents. Among these 7 tools, CRI, DSRSC, FRMC, CRPT  
 28 and RIT have been implemented worldwide through a collaboration between the developers of tools and  
 29 local partners, whereas BRIC and CART have been implemented mainly by end-users independently.

30

31 Table 2: overview of the 27 tools developed and used for measuring urban climate resilience.

Tool	Developer	End users	Copyright/ ownership	Resilience to what?	Urban only?	Implementation areas by developer	Nr of independent applications by users	Ref
Bassline Resilience Indicators for Communities (BRIC)	academia	National/local governments, planners	Can be implemented by users independently	Climate- related hazards	no	Entire USA counties	+10	<a href="#">link</a>
The Australian Natural Disaster Resilience Index (ANDRI)	academia (initiated by the national government)	Planners, emergency service providers, state fire departments	Can be implemented by users independently	Climate- related hazards	no	Entire Australia	0	<a href="#">link</a>

Coastal Community Resilience (CCR)	multi-orgs (initiated by USAID)	communities, NGOs, planners, government	Can be implemented by users independently	Coastal hazard	no	Indian ocean coasts	1	<a href="#">link</a>
Disaster Resilience Index (DRI)	multi-orgs	National/local government agencies	Can be implemented by users independently	All-hazards	yes	6 cities in developing countries	0	<a href="#">link</a>
PEOPLES	Academia (initiated by the US Federal government)	Planners, local authorities	Has only been used by developer	All-hazards	no	4 cities in the USA	0	<a href="#">link</a>
City Resilience Index (CRI)	ARUP (initiated by Rockefeller Foundation)	Local authorities	Can only be used in collaboration w tool developers	All-hazards	yes	80 cities worldwide	1	<a href="#">link</a>
ICLEI-ACCCRN Process	ICLEI/ACCCRN	Local authorities	Can only be used in collaboration w tool developers	Climate-related hazards	yes	46 Asian cities	0	<a href="#">link</a>
Climate and disaster resilience initiative (CDRI <sup>1</sup> )	multi-orgs	City gov officials	Can only be used in collaboration w tool developers	Climate-related hazards	yes	8+ Asian cities	2	<a href="#">link</a>
Natural Hazard Resilience Screening Index (NaHRSI)	EPA	US County authorities	Has only been used by developer	All-hazards	no	Entire USA counties	0	<a href="#">link</a>
Communities Advancing Resilience Toolkit (CART)	academia	Community organizations	Can be implemented by users independently	All-hazards	no	2 case studies (1 urban & 1 non-urban) in the USA	7	<a href="#">link</a>
Community Disaster Resilience Index (CDRI <sup>2</sup> )	Academia (initiated by the national government)	Unclear	Can be implemented by users independently	All-hazards	no	144 counties in the USA gulf coast	2	<a href="#">link</a>
Community Disaster Resilience Scorecard Toolkit (CDRST)	Torrens resilience institute (initiated by the national government)	Communities and planners	Can be implemented by users independently	All-hazards	no	9 communities in Australia	2	<a href="#">link</a>
The Conjoint Community Resiliency Assessment Measure (CCRAM)	academia	Local authorities	Can be implemented by users independently	All-hazards	no	+10 communities in 2 cities in Israel	1	<a href="#">link</a>
Disaster Resilience Scorecard for Cities (DRSC)	Multi-orgs (initiated by UNDRR)	Local authorities	Can only be used in collaboration w tool developers	All-hazards	yes	214 cities worldwide	2	<a href="#">link</a>
Enhancing resilience of communities and territories facing natural and na-tech hazards (ENSURE)	academia	Local authorities, planners	Can be implemented by users independently	All-hazards	no	3 regions in Greece, Israel and Italy	0	<a href="#">link</a>
Monitoring adaptation measures and climate resilience in cities (MONARES)	Adelphi Germany (initiated by the national government)	Local authorities, planners	Can be implemented by users independently	Climate-related hazards	yes	Ongoing – implementation not completed yet	0	<a href="#">link</a>

Resilience Inference Measurement (RIM)	academia	Unclear	Can be implemented by users independently	Climate-related hazards	no	52 counties in the USA	2	<a href="#">link</a>
ResilSIM	academia	Planners, emergency services	Has only been used by developer	Flooding	yes	2 cities in Canada	0	<a href="#">link</a>
Urban Community Resilience Assessment (UCRA)	WRI	Unclear	Can only be used in collaboration w tool developers	All-hazards	yes	3 cities in Brazil, Indonesia & India	0	<a href="#">link</a>
Flood Resilience Measurement for Communities (FRMC)	Multi-orgs (initiated by Z Zurich foundation)	NGOs, local authorities, planners and managers	Can only be used in collaboration w tool developers	Flooding	no	+300 communities in 20 countries worldwide	0	<a href="#">link</a>
ARC-D TOOLKIT	GOAL	NGOs, local authorities, planners and managers	Can be implemented by users independently	All-hazards	no	+225 communities in 13 developing countries	0	<a href="#">link</a>
Evaluating Urban Resilience to Climate Change (EURCC)	EPA	local level managers	Has only been used by developer	Climate-related hazards	yes	2 cities in the USA	0	<a href="#">link</a>
Comprehensive Disaster Resilience Index (CDRI <sup>3</sup> )	academia	NGOs, local authorities, planners and managers	Can be implemented by users independently	Climate-related hazards	no	Entire Italy	0	<a href="#">link</a>
Los Angeles County Community Disaster Resilience Project (LACCDR)	Research institute (initiated by the sub-national government)	LA county authority and planners	Has only been used by developer	All-hazards	no	Los Angeles county	0	<a href="#">link</a>
Resilience Assessment Benchmarking and Impact Toolkit (RABIT)	academia	Developing country strategists and practitioners	OA, developer provides training, unclear	All-hazards	no	1 city in Costa Rica & 1 rural district in Uganda	0	<a href="#">link</a>
City resilience profiling tool (CRPT)	UN Habitat	Local authorities, planners	Can only be used in collaboration w tool developers	All-hazards	yes	6 Cities worldwide	0	<a href="#">link</a>
Resilience Insight Tool (RIT)	Buro Happold Consultancy - BRE centre for resilience	City governments, international bodies and planners	Can only be used in collaboration w tool developers	All-hazards	yes	12 cities worldwide	0	<a href="#">link</a>

1

## 2 4.1. Decision cycle

3 The first part of our analysis explored the application of the above tools in the context of the different  
4 phases of the decision cycle. Figure 3 shows the findings: identifying problems and objectives, and  
5 decision-making criteria (e.g., whether to invest in and prioritize community flood resilience) mostly  
6 happen internally within organizations. The resilience measurement tools that we analysed support stages  
7 3-6 of decision cycle, some of which only focus on stage 3 (assessing the level of resilience that is the  
8 main objective of these tools) while others support multiple stages of decision cycle.

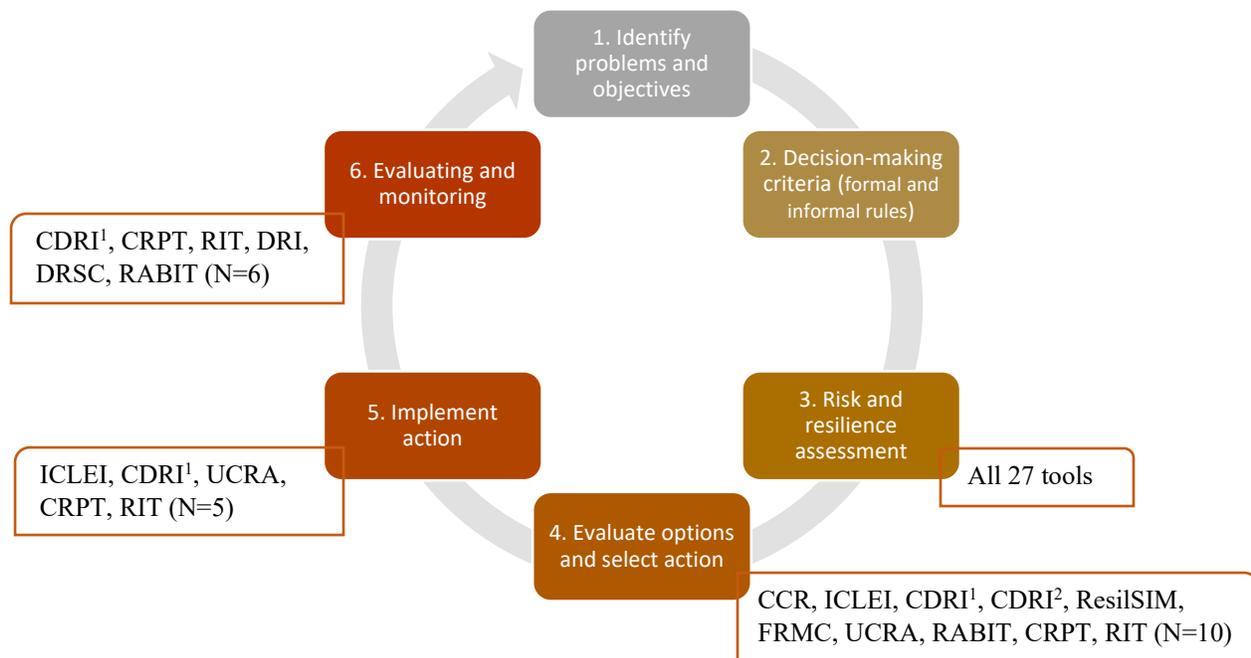


Fig 3: Tools supporting different stages of decision cycle.

**Risk and resilience assessment:** All the resilience measurement tools analysed utilise an indicator-based approach in which resilience is measured via a set of indicators or components covering various social, political, human, ecological, financial, and physical aspects of resilience. Some tools also recommend conducting a risk assessment at the beginning of the process to identify the level and distribution of exposure to hazard impacts and ensure the most important risks are being considered for the resilience measurement. DRSC, for example, prompts city stakeholders to identify “most probable” and “most severe” risk scenarios for single or multi-hazard events using the Quick Risk Estimation tool developed by UNDRR and Deloitte. ICLEI includes a subjective risk assessment methodology which assists prioritizing risks through a participatory and inclusive process. Although not many tools include a risk assessment process, it is widely acknowledged that for mapping out a path toward climate and multi-hazard resilience, it is essential to first obtain a comprehensive understanding of the locations, levels, and types of risks a city faces.

Most of the tools analysed (15 out of 27) are focused ‘only’ on assessing resilience (stage 3 of the decision cycle). In such tools, resilience indicators that score low are often interpreted as the most urgent challenges requiring interventions. However, decision-making about what actions can and should be taken and when depends on more complex environmental and contextual variables that should be considered.

The other 12 tools go beyond the resilience assessment stage and are explicitly designed to support other stages of a decision cycle such as options appraisal, implement actions, and evaluation and monitoring (stages 4-6)—see table 3.

**Option appraisal:** 10 tools support evaluating resilience building options prior to their implementation (stage 4) via a range of analysis and methods. ICLEI’s tool, for instance, evaluates and prioritizes resilience interventions based on their 1) feasibility (availability of technical expertise, relevant roles and responsibilities, political will, and financial capacity), 2) expected impacts (significant short, medium, and

1 long term impact on the targeted climate risk), as well as their alignment with characteristics of resilience  
2 (i.e. redundancy, resourcefulness, robustness, and rapidity). An important aspect of options appraisal  
3 being considered in the ICLEI tool is the integration of recommended interventions into existing city  
4 plans. This is particularly important as cities often have a comprehensive set of plans, ongoing programs,  
5 and projects at any one time. Success of the resilience projects depends on their alignment to the core  
6 vision and overarching programs of cities. In this phase, thus, local decision-makers can integrate the  
7 identified resilience strategies into existing departmental workplans. This also avoids duplications and  
8 wasted efforts.

9 CDRI<sup>1</sup>, CRPT, RIT, FRMC, and UCRA, on the other hand, evaluate and prioritize interventions and  
10 strategies via stakeholder workshops by using self-evaluation criteria and metrics developed by  
11 stakeholders. CRPT applies scenario processes to explore evolution of urban systems under three  
12 scenarios: current, trend, and the resilience scenarios. The current scenario is built upon the existing risk,  
13 exposure, and vulnerability of cities, the trend scenario includes the ongoing plans, programs, and projects  
14 of cities, and the resilient scenario is built upon the actions recommended as a result of the resilience  
15 assessment. RIT also utilizes scenario building to test the potential impacts of different strategies for  
16 increasing resilience capacities against the current baseline. This also enables insight into the costs and  
17 benefits of different options and for them to be compared with the cost of inaction.

18 ResilSIM is the only tool that applies a modelling and simulation method to support ex-ante evaluation of  
19 interventions by simulating the possible impacts of interventions in the model prior to actual  
20 implementation.

21 **Implementing actions:** Following stage 4, some tools go further and support developing a short- and  
22 long-term resilience plan and program to facilitate the implementation of resilience interventions, as well  
23 as to support long-term city resilience planning. While stage 4 (i.e., options appraisal) evaluates the  
24 availability and access to crucial capacities and resources, stage 5 (i.e., implementing actions) focuses on  
25 creating or improving capacities and resources required for implementing resilience actions. CRPT,  
26 UCRA, RIT, CDR<sup>1</sup> and ICLEI, for example, generate a complete and detailed roadmap of the  
27 stakeholders, responsibilities, institutional mechanisms, technical support, policy changes or fund raising  
28 needed for the implementation of the identified resilience strategies. In UCRA, the local partners then  
29 submit their resilience plan to the relevant departments within the city to determine the next steps. This is  
30 also another step, in which decision-makers can further align the resilience projects and strategies with the  
31 key city planning objectives to maximise the chances of success and return on investments (e.g., in  
32 UCRA).

33 **Evaluation and monitoring:** There are a few tools developed particularly to support monitoring and  
34 evaluating the impacts of cities' activities on climate resilience. Some of these tools take a benchmarking  
35 approach in which progresses of cities in building or enhancing resilience (as a whole, not as individual  
36 measures/actions) is measured against a set of pre-defined goals or standards. DRSC, for instance, assists  
37 local governments in monitoring and reviewing progress and challenges in the implementation of the  
38 Sendai Framework for Disaster Risk Reduction: 2015-2030. It is, therefore, structured around UNDRR's  
39 ten essentials for making cities resilient. DRI, similarly, establishes benchmarks and evaluates progress on  
40 the mainstreaming of risk reduction and resilience approaches in the cities' development policies and  
41 processes.

42 CRPT, RIT, CDRI<sup>1</sup> and RABIT, on the other hand, have a project-based approach, meaning specific  
43 monitoring and evaluation criteria are developed in each action plan to measure the progress of that  
44 project/intervention over time (i.e., if and how the project is satisfying its specific pre-defined goals).

1 RABIT is particularly designed to support practitioners in developing countries to evaluate and monitor  
2 the impact of their development interventions on community resilience. This tool requires practitioners to  
3 identify how each individual project will be/has been contributing to the different attributes of resilient  
4 systems either during the initial set-up of goals for interventions or after the implementation of  
5 interventions. The former establishes the key areas of focus in each intervention to build resilience, while  
6 the latter informs future planning/decision-makings based on lessons learned.

7 Additionally, many tools recommend that the resilience measurement be repeated over time in order to  
8 monitor and evaluate changes. However, only a few of the tools have actually been implemented more  
9 than once (e.g., BRIC, FRMC, CDRST, LACCDR, RIT and PEOPLE – see table 3). However, if a tool is  
10 applied repeatedly over time, it does not automatically mean that it serves as a monitoring and evaluation  
11 process in and of itself. Overall, comparing various aspects of resilience at different time periods and  
12 associating them with specific intervention remains a challenging task, particularly given the qualitative  
13 and subjective nature of data collection methods used in such tools. Thus, most of the tools remain one-  
14 off measures in most of the cities, which does not support understanding of the evolutionary nature of  
15 resilience and monitoring impacts of resilience interventions.

16

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Table 3: Evaluation criteria for assessing how resilience measurement tools support decision-making and planning for urban climate resilience. ✓= addressed, ✗ = not addressed or not enough information provided.

Tool	Decision-cycle stage(s)	Repeated measurement (achieved in practice)	Proactive approaches		Long-term climate info use		Participatory planning	
			Corrective Risk reduction	Prospective risk reduction	Climate change indicator(s)	Climate change information use in methodology	Participatory planning indicator(s)	Participatory approach in methodology
BRIC	3	✓	✗	✗	✗	✗	✓	✗
ANDRI	3	✗	✓	✓	✗	✗	✓	✓
CCR	3&4	✗	✓	✓	✓	✗	✓	✓
DRI	3&6	✗	✓	✓	✗	✗	✓	✓
PEOPLES	3	✓	✗	✗	✗	✗	✗	✓
CRI	3	✗	✓	✓	✗	✗	✓	✓
ICLEI	3,4&5	✗	✓	✗	✓	✓	✓	✓
CDRI <sup>1</sup>	3,4,5 & 6	✗	✓	✓	✓	✗	✗	✓
NaHRSI	3	✗	✗	✗	✗	✗	✗	✗
CART	3&4	✗	✗	✗	✗	✗	✗	✓
CDRI <sup>2</sup>	3	✗	✓	✓	✗	✗	✗	✗
CDRST	3&6	✓	✗	✗	✗	✗	✓	✓
CCRAM	3	✗	✗	✗	✗	✗	✗	✓
DRSC	3	✗	✓	✓	✓	✗	✓	✓
ENSURE	3	✗	✗	✗	✗	✗	✗	✓
MONARES	3	✗	✗	✗	✓	✗	✓	✓
RIM	3	✗	✗	✗	✗	✗	✗	✗
ResilSIM	3&4	✗	✗	✗	✗	✗	✗	
UCRA	3,4&5	✗	✗	✗	✓	✓	✓	✓
FRMC	3&4	✓	✓	✗	✓	✗	✓	✓
ARC-D	3	✗	✓	✓	✓	✗	✓	✓
EURCC	3	✗	✓	✓	✓		✗	✓
CDRI <sup>3</sup>	3	✗	✗	✗	✗	✗	✗	
LACCCR	3	✓	✗	✗	✗	✗	✗	✓
RABIT	3,4&6	✗	✓	✓	✓	✓	✗	✓
CRPT	3,4,5&6	✗	✓	✗	✗	✓	✓	✓
RIT	3,4,5&6	✓	✗	✗	✓	✓	✗	✓

## 4.2. Enablers of adaptive and transformative decision-making

The second part of our analysis explored which resilience capacities (i.e., coping, adaptive and transformative capacities) the tools support and how (figure 2). Our analysis revealed that most of the tools particularly lack recognition of proactive approaches and climate information use in assessing resilience of cities. Therefore, some tools may influence adaptation and transformational decision-making more than others by providing insights and recommendations on proactive strategies, long-term climate information use, and participatory planning (table 4).

Table 4: Tools supporting different enablers of transformative decision-making. Percentages represent the proportion of the tools that incorporate each element.

Enablers of adaptive and transformative decision-making	Tools incorporating each element
Proactive approaches	ANDRI, CCR, DRI, CDRI <sup>1</sup> , DRSC, ARC-D, EURCC (25%)
Long-term climate info use	ICLEI, UCRA, RABIT, RIT (14%)
Participatory planning	ANDRI, CCR, DRI, CRI, ICLEI, CDRST, DRSC, MONARES, UCRA, FRMC, ARC-D, CRPT (44%)

**Proactive strategies:** Among the tools analysed, we only found 7 tools that have a strong focus on proactive strategies for cities to reduce impacts of climate change (i.e., EURCC, ANDRI, CCR, DRI, CDRI<sup>1</sup>, DRSC, and ARC-D). These 7 tools have adopted different types of indicators/parameters/questions to measure various aspects of risk reduction including corrective and prospective risk reduction in addition to post-event response and recovery. While both corrective and prospective risk reduction strategies support proactive and ex-ante risk reduction and adaptation, prospective risk reduction measures are key in enabling transformation capacities of cities. Indicators used in these 7 tools to measure prospective risk reduction strategies of cities are generally focused on:

- The application of smart and adaptive architecture and urban design/planning (e.g., multi-functional landscapes for urban flood control and urban tree canopy cover, green roofs, urban ventilation, and tree shading programs to lessen urban heat island effects),
- incorporation of DRR and adaptation in existing urban plans and policies (e.g., zoning, land use, and urban development plans), urban design (e.g., urban morphology, urban green space, and sustainable drainage system), building codes, and resilient housing,
- incentives for the implementation of prospective risk reduction measures (e.g., government mechanisms to purchase lands on floodplains and financial support for integrating green infrastructure into urban infrastructure planning), and
- enforcement mechanisms (e.g., insurance mechanisms that explicitly discourage rebuilding of properties on floodplains)

Among these 7 tools, DRI, CDRI<sup>1</sup>, DRSC, and ARC-D were developed based on the Sendai Framework for Disaster Risk Reduction and the UNDRR's 10 essentials for making cities resilient, all of which focus on prioritizing pro-active risk reduction and adaptation strategies. These 7 tools also assess the human and social capacities of communities which can influence prospective risk reduction behaviour in the long run. For example, education and training programs for improving 1) awareness around current and future risk, and 2) compliance with risk reduction policies and principles.

1 **Long-term climate information:** Surprisingly, out of the 27 tools, only 11 tools include at least one  
2 indicator that assesses understanding of climate change or utilization of climate change  
3 information/scenarios in city planning (table 3). UCRA and FRMC, for example, measure level of  
4 perceived climate risk (i.e., impact of climate change on future risks) by communities. ARC-D, CCR and  
5 DRSC have indicators that assess the extent to which local authorities have access to and use existing  
6 climate information to inform local decision-making. RABIT assesses whether local communities have  
7 access to climate change awareness training and educational resources. CDR<sup>1</sup> assesses incorporation and  
8 mainstreaming of climate change uncertainties and adaptation in cities' disaster risk management  
9 planning, land use and environmental plans, housing and transportation policies, and school education  
10 curriculum. MONARES evaluates the climate change adaptation aspect in city development plans as well  
11 as the existence of climate change working groups in local governments. This tool also measures whether  
12 ICTs used to inform local decision-making processes also facilitate access to different types of climate  
13 change information e.g., projections and forecasts.

14 Some tools such as ICLEI, NaHRSI, RABIT, UCRA, and RIT support local governments in developing  
15 climate exposure projections and applying them in their resilience assessments. Climate information used  
16 for such projections includes information on past climate-related events and future climate change trends  
17 and projections. ICLEI provides local governments with detailed guidance on the potential climate data  
18 sources and the process of collecting and analysing the data. NaHRSI utilizes the climate information  
19 provided by the National Climate Assessment and 100 Resilient Cities report together with discussions  
20 with climate change experts in regional agencies. RIT utilizes climate exposure projections to measure the  
21 changing resilience demand over a period of 15 years (2015-2030). Projections are based on various  
22 models provided by OPCC, IMF, WHO, United Nations, OECD, and HM ONS. It is, however, well  
23 acknowledged that the projection horizon year for each city/country depends on the availability of climate  
24 data and that the further into the future the projection is made, the less confidence can be placed in the  
25 results (Collins et al., 2013).

26 In addition, ICLEI and ARC-D include scenario building with local stakeholders as a part of the resilience  
27 assessment process which helps identifying and planning for future climate risks and dealing with  
28 uncertainties. ARC-D, for instance, utilized the climate scenarios and identifies the priority risk scenarios  
29 based on the prioritization of shocks and stresses, the exacerbating effect of stresses on shocks, the degree  
30 of loss and damage caused by the shocks and the communities' coping capacity to overcome this. In any  
31 given assessment in the field, the user can choose one multi-hazard risk scenario or up to two single-  
32 hazard risk scenarios (i.e., assess two different hazards in the same assessment).

33 **Participatory planning:** 21 of tools apply at least one type of public engagement method to collect  
34 primary data for measuring resilience (e.g., household survey, key informant interview and focus group  
35 discussion). 12 of this subset apply a combination of interviews, workshops, and surveys to maximize the  
36 community engagement during the process. At the same time, 13 tools are found that evaluate the level of  
37 community participation in the local decision-making and planning of cities (table 3). Such measures  
38 include assessing citizen participation in 1) disaster awareness and capacity building training and  
39 education (e.g., DRR and adaptation awareness activities), 2) rating and assessing risks, vulnerabilities,  
40 and resilience, 3) decision-making for DRM and climate adaptation interventions, and 4) developing,  
41 implementing, and monitoring plans, policies, and programs.

42 In addition, 6 tools (i.e., CART, CDRI<sup>2</sup>, CDRI<sup>3</sup>, ENSURE, RABIT and PEOPLES) rely solely on  
43 measuring the level of community engagement in social networks and society activities. Such  
44 engagements are usually use and proxies for rapid access to warnings and information about emergency  
45 actions, and increasing community assistance in the emergency response phase (Menoni et al., 2012;

1 Parker and Handmer, 1998)—i.e. only short-term adaptation and response activities. Yet, long-term  
2 transformational adaptation and DRR activities require direct engagement of communities in city  
3 planning and programming.

4

#### 5 **4.3. Does measurement of resilience lead to resilience actions?**

6 Finally, we reflect on key-informants' perspectives to assess if and how resilience measurement tools  
7 have been actually used to support decision-making. The 12 key-informants were involved in  
8 implementation of four of the most widely applied tools, i.e., ICLEI, DRSC, CRF, and FRMC, in over  
9 100 cities across the world. Drawing on our key informant interviews, we elaborate on 1) the impacts of  
10 applying such tools on the decision-making process, 2) if and what resilience actions have been taken as a  
11 result of measuring resilience, and 3) barriers and challenges of taking resilience actions recommended by  
12 tool. It should be noted that interviews were not set out to evaluate quality and credibility of each  
13 individual tool for supporting decision-making. Instead, the aim of interviews was to gain insights (base  
14 on practical examples) on how the whole concept of measuring resilience can support local decision-  
15 making and taking actions for urban climate resilience.

#### 16 **Impacts on decision-making process**

17 Most of the key informants argued that resilience measurement tools are supposed to encourage resilience  
18 thinking and prioritizing resilience activities in the process of decision-making rather than providing  
19 solutions for decision-makers. Therefore, they pointed out some of the less tangible but long-term impacts  
20 of resilience measurement activities on decision-making (based on their experiences and observations) as  
21 follows:

22 *Providing a holistic view of risk and resilience:* 9 out of 12 interviewees highlighted that gathering  
23 various sorts of data in one place and evaluating resilience through different capitals/systems was a major  
24 benefit of using resilience measurement tools, which would have not been normally considered by the city  
25 actors (due to lack of access to information or resources). "Using the tools have particularly encouraged a  
26 focus on the social and natural aspects of resilience that are often neglected under the shadow of the  
27 physical and hydrological aspects" (KI7). Many interviewees argued that such holistic thinking was  
28 brought about by the functionality of tools that allow inputting different perspectives, knowledge, and  
29 data from various stakeholders and sectors (KI1, 2, 3, 5&8). This also encourages system-thinking among  
30 the city actors: "The process definitely brought new questions into the decision-makers minds, if nothing  
31 else, about what needs to be done apart from what they had always focused on" (KI3).

32 *Increasing public engagement and awareness:* 8 interviewees argued that the process of implementing  
33 tools lead to an increase in public engagement in the decision-making process for climate resilience and  
34 raising awareness about the level and locations of climate risks. This is particularly the case for the tools  
35 that have a participatory approach in collecting and evaluating data. In some cities this has been identified  
36 as best practice that should be replicated in future decision-making processes. "With or without the tool  
37 they would have built the dam any way (...), but what they did after implementing the tool was that they  
38 did a lot of public hearings and meetings and talking to the residents about their ideas and concerns over  
39 this project, which was suggested by tool (KI)"

40 *Supporting understanding resilience as more than a vague concept:* 6 interviewees also highlighted the  
41 role of tools in helping city actors to familiarize themselves with climate and disaster resilience through  
42 tangible measures relevant to their local context. This has particularly claimed to be effective in tools that

1 link resilience to frameworks that local decision-makers are already familiar with and work with, such as  
2 the disaster risk management cycle, risk reduction and adaptation targets and sustainable development  
3 goals, facilitating understanding and application of resilience in a day-to-day decision-making process  
4 (KI1,10,11,12).

5 *Familiarizing city actors with uncertainty and unexpected changes:* Finally, 2 interviewees explained how  
6 the focus of resilience measurement tools on uncertainties caused by climate change supported city actors  
7 to realise the need for transformative decision-making rather than incremental planning and management.  
8 “Measuring resilience and identifying resilience challenges often shows that building resilience is about  
9 the long-term uncertain future that cities need to be prepared for, whereas most of the information  
10 supporting decisions being made are based on the historical data or short-term projections” (KI1&4).

### 11 **What actions have been taken?**

12 The interviewees also explained a few avenues by which resilience measurement results led to tangible  
13 actions/interventions; below we outline the most common outcomes:

14 *Strategies and policies:* 6 interviewees described at least 15 cities that used resilience measurement tools  
15 and their results to inform the creation or update of strategies, policies, and guidance reports. In most of  
16 such cases, the creation of strategies was not the direct output of the tool, rather, the tool and its results  
17 triggered or facilitated discussions around including urban resilience components into existing policy  
18 documents (e.g., in Santa Fe, Argentina, Addis Ababa, and Houston). This has been particularly impactful  
19 in countries where city level stakeholders (i.e., the main users of tools) had the power to influence  
20 national level debates on policy developments.

21 *Informing urban planning and design:* In addition to policies and strategies, two interviewees particularly  
22 pointed out how the resilience measurement results have also been used in three cities to inform and  
23 improve the urban and spatial planning and design of cities: the city of Manchester used results of CRI  
24 analysis to inform their cycling and walking, and in San Francisco, US and Amadora, Portugal results  
25 were used to improve city master plans by adding more green space and avoiding development projects in  
26 the risk prone areas.

27 *Increase investments:* in 22 cities described by 8 interviewees, the tools results were used to support  
28 funding applications or to allocate and reallocate local budgets for implementing resilience projects  
29 recommended by the tools (e.g., in Cilacap, Indonesia; Irga city in Philippines; greater Manchester, UK;  
30 Java, Indonesia; Lowestoft, UK; and many cities in Mongolia). In some countries, implementing  
31 resilience measurement was a requirement for cities wishing to apply for funding whereas in others it has  
32 been a proactive approach of city governments (KI11).

33 *Connecting and sharing information with other cities:* 5 interviewees argued that many cities also used  
34 the outcomes of tools to share their experiences and learn from other cities who applied the same tool.  
35 This was particularly the case in the UNDRR and 100 Resilient Cities programs, where a network of  
36 cities was already established before the development of the tools (i.e., DRSC and CRI) which accelerated  
37 sharing information and learnings among the cities involved in the program. Cross-national connections  
38 of urban information via city networks have been shown to accelerate opportunities for proactive and  
39 well-informed decision-making (Acuto, 2018; Hughes et al., 2020).

### 40 **Challenges and barriers for resilience actions**

41 In addition to the content of tools that may or may not support resilience building (as described in section  
42 4.2), there are some environmental and contextual barriers and challenges which can hinder or constrain

1 implementation of resilience actions. Our end-user interviews revealed five main barriers and challenges  
2 for building resilience found in various cities and countries. These are:

3 *Prioritisation of most recent risks:* 10 out of 12 interviewees mentioned that existence of other city  
4 priorities, including city development programs, and coping with the most recent risks, often take the  
5 attention of city governments away from climate risk reduction and adaptation activities. This is  
6 particularly the case in cities facing low frequency-high severity risks of climate change such as severe  
7 flood events that may not occur often, but when they do, have profound consequences. “The biggest  
8 obstacle is when, for example, in Semarang (Indonesia) you try to convince local government to plant  
9 mangroves in the riverside which may impact half a million people but then you get big businessmen  
10 coming with their hotel and shopping centre projects with tens of millions of dollars financial benefits for  
11 the city. They can easily wipe your progresses out (...)” (KI4). “A recent and clear example is the  
12 COVID-19 pandemic emergency which has acutely overshadowed governments plans and programs for  
13 climate adaptation.” (KI1) It has also been discussed that that governments that focus mainly on  
14 emergency response, coping and protection strategies are more likely to have a short-term reactive  
15 response, and as a result, suddenly shift their focus from existing long-term risks to the most recent and  
16 urgent risks (KI1, 4, 5, 6, 12).

17 *Top-down governance system and lack of local power:* Six of the interviewees who have worked with  
18 cities in countries that have a centralized government system mentioned that the local authorities in such  
19 cities have little or no power to change plans and policies or (re)allocate financial and human resources  
20 toward new activities, and therefore, have little responsibility and accountability for the creation or  
21 mitigation of risks related to climate change and disasters. In such circumstances, “...the city  
22 governments are less willing to consider transformative decisions and actions in favour of continuing with  
23 the business-as-usual strategies defined by the central government”.

24 *Political instability:* Three of the interviewees who have worked with cities experiencing frequent and  
25 significant turn-over in the national and/or local leadership argued that such instabilities does not allow  
26 for the establishment of the long-term transformational strategies required for building resilience (KI 1, ,  
27 11). Such political instability at the national and city government levels is a consequence of political  
28 infighting for the gain of political party over others, rather than a focus on meeting the needs of  
29 communities (Pasquini et al., 2015). Political instability leads to frequent changes and redirection of  
30 municipal actions and resources (and therefore, loss of human capacity built in past periods), replacement  
31 of public actors based on their political alignments rather than expertise, and more importantly,  
32 incapability of municipalities to develop and implement long-term strategies (Pasquini et al., 2015;  
33 Nightingale, 2017).

34 *Lack of transparency:* Three interviewees argued that city governments with low transparency are  
35 generally less willing to publicly communicate gaps and limitations, acknowledge and act upon them,  
36 whereas cities with transparent and open government systems often take a self-critical approach to  
37 assessing and communicating the outcomes of their activities with the public, and therefore, are more  
38 likely to uptake different and transformative measures (change the land use of flood prone areas, invest on  
39 green infrastructure instead grey infrastructure, etc.). It has also been acknowledged that the  
40 implementation of resilience actions is only possible through the partnership of the local and political  
41 leaders willing to bring about change and transformation in their city planning and governance systems.

42 *Rigid departmentization:* As resilience is a multi-dimensional concept, improving city resilience requires  
43 addressing multiple systems and multi-sectoral challenges (i.e., related to social, human, natural, physical  
44 and financial systems) which calls for a strong collaboration and coordination among different public

1 sectors and departments within a city. However, a lack of a whole-of-government approach and cross-  
2 cutting cooperation among different sections of a city government have been highlighted by two  
3 interviewees as another crucial barriers in implementing resilience interventions. “This particularly  
4 becomes a deterrent factor in implementing resilience interventions when there are different and  
5 sometimes conflicting interests, preferences, and priorities across different sectors” (KI4).

## 6 **5. Conclusion**

7 Resilience measurement tools have been developed, implemented, and studied for a long enough time that  
8 they can be now evaluated for their application in supporting decision-making. In this paper, we found  
9 that only about a third of existing urban resilience measurement tools support implementation at any  
10 stages (i.e., option appraisal, implementation planning, and monitoring and evaluation). In order to  
11 support resilience action, it is important to acquire a deep understanding of the governance system and  
12 structure, human and financial resources and the formal and informal norms and rules in each context.  
13 This can also help facilitate an effective integration of resilience thinking into the existing action planning  
14 of cities.

15 Moreover, building resilience is about enhancing coping, adaptive and transformative capacities  
16 altogether so that the most relevant and effective strategies can be used at each stage of urban climate risk  
17 management. However, our analysis shows that most of the urban resilience tools analysed are designed  
18 in such a way to evaluate and, thereby, encourage coping capacities rather than adaptive and  
19 transformative capacities. Out of 27 tools analysed, 20 tools have a primary focus on measuring response  
20 and recovery activities (i.e., reactive strategies) and 16 tools do not include any climate change impacts in  
21 their analysis, and therefore, measure resilience only based on current climate risks. This lack of  
22 recognition of proactive risk reduction measures and the disregard of future climate change impacts are  
23 likely to lead to prioritisation of quick fix solutions instead of pointing towards the longer-term resilience  
24 interventions.

25 Our analysis shows that most of the urban resilience measurement tools incorporate participatory  
26 approaches for assessing resilience and/or evaluating the decision-making process of cities. This is a  
27 positive sign and indicates a general understanding of the complexity and subjective aspects of resilience  
28 which require engagement of a variety of stakeholders for evaluation of and decision-making for  
29 resilience. This is an important principle of community resilience and can not only help to generate  
30 awareness but also buy-in and support for measures while also helping to ensure that measures are  
31 targeted and in line with community needs. While we acknowledge that there is no perfect tool, we  
32 encourage users and developers to have a close look at the frameworks and approaches of tools identified  
33 in this research with strong consideration of proactive strategies, climate information use, and  
34 participatory planning.

35 We acknowledge that having these three elements (i.e., considering proactive strategies, utilizing climate  
36 information, and integrating participatory planning) in the process of decision-making might not  
37 guarantee but could encourage transformational decisions and actions over incremental ones. Importantly  
38 there are also wider factors that influence decision-making in the municipal context: National and local  
39 governance structures, human and financial resources, political will and interests, and priority of most  
40 recent risks were mentioned as the most important contextual barriers for implementing resilience actions.  
41 Transition from resilience assessment to resilience action, therefore, requires consideration of such  
42 contextual aspects in evaluation and selection of solutions. Future studies could explore this in greater  
43 detail to help inform design and implementation of transformative decision-making support tools. This  
44 would ideally include the resources, process, roles, and actors needed for such a transition. In addition,

1 further research is required to study how the conceptual and methodological differences of tools (e.g.,  
2 framework and types of indicators used, data collection methods, using qualitative and quantitative data,  
3 unite of measurement, single-hazard vs multi-hazard, grading methods, subjective vs objective evaluation  
4 of measures, etc.) may impact an effective decision-making process.

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Name	institute	Tool applied	Countries & cities
Key Informant 1	ISET	ICLEI & CRI	Directly involved: more than 10 cities in Vietnam
Key Informant 2	UNDRR	DRSC	Directly involved: 21 cities in Mongolia including Ulaanbaatar, Darkhan, and Erdenet (the major cities in Mongolia)
Key Informant 3	Swedish Civil Contingencies Agency	DRSC	Directly involved: Arvika and Jonkoping in Sweden
Key Informant 4	Mercy corps	ICLEI	Directly involved: more than 10 Asian cities
Key Informant 5	Police and civil protection in Amadora, Portugal	DRSC	Directly involved: Amador in Portugal
Key Informant 6	50L Home Coalition at WBCSD	CRI	Directly involved: Copenhagen, Denmark Coordinated: 10-12 of cities including Hongkong, Shanghai, Madrid, Santiago, Addis Ababa, Santa Fe, Houston, Manchester, Cape Town, etc.
Key Informant 7	UNDRR	DRSC	Directly involved: 56 cities in 5 countries (Philippines, Bangladesh, India, Nepal, and Indonesia)
Key Informant 8	Chief Resilience Officer of Athens	CRI	Directly involved: Athens, Greece
Key Informant 9	UNDRR	DRSC	Directly involved: Ningbo and Chengdu in China
Key Informant 10	100 resilient cities	CRI	Indirectly involved in developing tool
Key Informant 11	UNDRR	DRSC	Directly - 7 cities: San Juan de Lurigancho in Peru, Tegucigalpa in Honduras, Santo Domingo Este in Dominican Republic, Cordoba I Argentina, Portoviejo and Guayaquil in Ecuador, and Guatemala City in Guatemala
Key Informant 12	ZFRA	FRMC	Directly involved: Lowestoft (UK) - Cologne & Remscheid (Germany)