AGU ADVANCING EARTH AND SPACE SCIENCE

Earth's Future

RESEARCH ARTICLE
10.1029/2020EF001508

An Integrated Framework to Streamline Resilience in the Context of Urban Climate Risk Assessment

A. Urquiza[1,2,3], C. Amigo[1,3,4], M. Billi[1,3,5,6], R. Calvo[1,3,7], L. Gallardo[1,8], C. I. Neira[1,5], and M. Rojas[1,8]

[1]Center for Climate and Resilience Research CR[2], Santiago, Chile, [2]Social Sciences Faculty, University of Chile, Ñuñoa, Chile, [3]Energy Poverty Network, Santiago, Chile, [4]University of Chile, Santiago, Chile, [5]Núcleo de Estudios Sistémicos Transdisciplinarios, Ñuñoa, Chile, [6]School of Government, Adolfo Ibáñez University, Santiago, Chile, [7]Pontificia Universidad Católica de Chile, San Joaquín, Chile, [8]Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile

Key Points:

- We advance six analytical distinctions and a methodological pipeline to streamline resilience in urban climate risk assessment
- Our framework promotes integrated and interdisciplinary efforts toward climate-sensitive urban risk assessment and planning
- Polycentric governance is required to balance autonomy and coherence across the systems constituting urban Systems-of-Systems

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

M. Billi,
marco.dg.billi@gmail.com

Citation:

Urquiza, A., Amigo, C., Billi, M., Calvo, R., Gallardo, L., Neira, C. I., & Rojas, M. (2021). An integrated framework to streamline resilience in the context of urban climate risk assessment. *Earth's Future*, *9*, e2020EF001508. https://doi.org/10.1029/2020EF001508

Received 4 FEB 2020
Accepted 12 JUN 2021

Author Contributions:

Conceptualization: A. Urquiza, C. Amigo, M. Billi, R. Calvo
Data curation: C. I. Neira
Funding acquisition: L. Gallardo, M. Rojas
Investigation: M. Billi, C. I. Neira
Methodology: A. Urquiza, C. Amigo, M. Billi, R. Calvo
Project Administration: A. Urquiza
Supervision: A. Urquiza

Abstract

Cities are increasingly acknowledged as crucial when facing climate change—and the environmental crisis more in general—, offering challenges and opportunities in terms of both mitigation and adaptation. Climate change-sensitive urban governance requires proactive, integrated, and contextualized approaches, making room for the complex, multilayered, multiscalar, and dynamic processes constituting a city. The notion of "resilience" has been acquiring growing recognition as a flexible and powerful concept to respond to these challenges. Resilience itself, however, is also a polysemic notion, often treated as little more than a catchword or a wishful aim or superimposed with other climate-related terms, such as risk, vulnerability, or adaptation. To promote a stronger integration among different problem-settings and epistemic communities, this paper advances six analytical distinctions aiming to provide structure and articulation to existing definitions of the concept of "resilience." Likewise, it offers an integrated analytical framework and methodological pipeline to streamline resilience analysis in the context of urban climate risk assessment. The framework is specially defined to link up with the definition of climate risk provided by the Intergovernmental Panel on Climate Change (IPCC) latest Assessment Reports and is illustrated through examples derived from the recent experience of the Chilean Climate Risk Atlas.

Plain Language Summary

This paper offers an integrated terminology, analytical framework, and procedure to measure and predict a city's resilience in the face of climate threats. Based on a thorough review and discussion of the literature on the topic, the proposal is designed to articulate existing approaches, usages, and interpretations of the concept. It aims to guide scholars, practitioners, and policymakers to employ resilience as a tool for urban planning and governance.

1. Introduction

Roughly 55% of the world's population resides in urban areas (United Nations, 2019a), a number expected to rise steadily during the next decades (Ritchie & Roser, 2018). Not only do cities generate a significant source of the world's Greenhouse Gas (GHG) emissions (Moran et al., 2018), but they also influence and mediate the effects of climate change on society (McCarthy et al., 2010). This fact urges to develop an integrated approach to design climate-sensitive urban governance, i.e., able to enact mitigative, adaptive, and transformative efforts in the face of a changing planet (Bai, 2018; Brondizio et al., 2016; Grimm et al., 2008). However, up to this point, urban governance remains a strongly fragmented field targeted by a variety of epistemic communities encompassing urban planning, disaster management, and climate vulnerability, to quote just a few (Wolfram et al., 2017).

The Intergovernmental Panel on Climate Change (IPCC) has taken important steps toward integrating these research communities by providing a general framework to understand climate risk unifying previously heterogeneous definitions. Particularly, the 2019 Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) understands climate risk as to the interplay within a given territory, among a climate hazard—i.e., the expected incidence of a climate event or condition—, with the exposure and sensitivity of individuals and communities as well as goods, infrastructures, processes, and services they value in

10.1029/2020EF001508

Validation: L. Gallardo, C. I. Neira, M. Rojas
Visualization: C. Amigo
Writing – original draft: M. Billi
Writing – review & editing: A. Urquiza, R. Calvo, L. Gallardo, M. Rojas

the face of this hazard (Abram et al., 2019). Furthermore, the SROCC also explicitly addresses the notion of "resilience" in the context of climate risk assessment. Thereby, it provides an important step toward a more "holistic" understanding of climate risk and a deeper appreciation of how different kinds of hazards and vulnerabilities may combine in generating system-wide risks and impacts.

IPCC's move toward resilience mirrors the growing attention that the concept has drawn lately within the context of urban governance. This, in turn, has inspired the quest for a new paradigm in city planning pursuing sustainability and climate mitigation while also fostering adaptation of cities to climate and environmental transformations (Desouza & Flanery, 2013; Eraydin & Tasan-Kok, 2013; Fu & Zhang, 2017; Meerow et al., 2016). Gradually, the notion of "urban resilience" has gained ground both as a way to problematize the application of the concept of resilience to city planning (Pizzo, 2015; Vale, 2014) and to organize variables and indicators to operationalize these notions in concrete applications (Desouza & Flanery, 2013; Ouyang et al., 2012). Likewise, urban resilience has become one of the leading pillars of action for a variety of initiatives advanced by various bodies including supranational institutions such as United Nations Human Settlements Programme (UN-Habitat), the International Strategy for Disaster Reduction (UNISDR), and the Global Facility for Disaster Reduction and Recovery, international financial entities such as The World Bank and the Interamerican Development Bank, "networks of cities" such as International Council for Local Environmental Initiative (ICLEI, now Local Governments for Sustainability), C40 Cities Climate Leadership Group and Cities Alliance and private nonprofit organizations such as the Rockefeller Foundation. Aligning efforts to support sustainable and resilient cities is the explicit goal guiding the combined efforts of the Medellín Collaboration formed at the World Urban Forum 2014 and reaffirmed later during the Quito conference.

The growing interest granted to the concept of resilience is partly due to the ability to act as a "boundary object" cutting across research fields and perspectives while fostering coherence and collaboration at the same time among them (Baggio et al., 2015; Brand & Jax, 2007) and thus, potentially grounding an integrated and holistic perspective on urban governance. However, precisely because of this semantic heterogeneity, the concept entails various definitions and approaches, hampering comparability across studies and approaches (Hosseini et al., 2016; Linkov & Trump, 2019). The literature on resilience today spans multiple disciplines, including Material Sciences, Psychology, and Economics, Disaster Management, Ecology. Each has developed its specific concept understandings and usage (Olsson et al., 2015; Schiappacasse & Müller, 2018; Thoren, 2014; Xue et al., 2018). Likewise, with a few recent exception (Abram et al., 2019; Galaitsi et al., 2020; Linkov et al., 2018) literature tends to lack clarity on how resilience connects, in practice, with other climate-related concepts such as risk, vulnerability, adaptation, planning, and sustainability (Elmqvist et al., 2019; Leichenko, 2011). In the absence of a reasonably shared understanding of these relationships, resilience may end up doing little more than adding yet another layer of complexity to urban governance.

The challenge is to construct a conceptual framework broad enough to do justice to the various interpretations to open the concept to an inclusive and plural interdisciplinary debate while recognizing their differences and providing means to articulate these differences. A particularly daunting task is to make the concept accessible and attractive to social science scholars. Social scientists' contribution to the understanding and management of climate risks is increasingly recognized (Billi et al., 2019). However, social science scholars have traditionally been less prone to enter this field and have particularly shown suspicion concerning the notion of "resilience," precisely for its inability to dialogue with standing ideas within the disciplinary field. Along these lines, concerns have been raised, for instance, in Olsson et al. (2015), about simply "imposing" those concepts within social sciences instead of offering a translation or reinterpretation—which is what we are attempting to do.

In the awareness of these considerations, this paper endeavors to illustrate and discuss a system-based analytical framework and methodological pipeline aiming at streamlining resilience in the context of urban climate risk assessment. More specifically, we aim at (a) specifying and organizing different meanings resilience adopts in the specialized literature when applied to cities; (b) clarifying the relationships between resilience, risk, and vulnerability; and (c) proposing a guide for climate risk and resilience assessment in cities, for climate-sensitive urban governance. We hope that our framework and pipeline can serve as an interface between multiple disciplines (engineering, social sciences, and Earth sciences) as well as between science and policy, and also as a way to increase collective Futures Literacy in the face of global risks and climate change (UNESCO, 2019).

The paper is organized into four sections. Section 2 offers a brief but systematic review of the academic scholarship linking resilience to cities so as to identify the specific challenges associated with an integrated perspective on urban resilience. Section 3 advances six analytical distinctions aiming to answer these challenges and providing structure to resilience analysis. Each is illustrated through a discussion of the relevant literature. Section 4 places these distinctions together in an analytical framework and methodological pipeline integrating resilience within urban climate risk assessment. To illustrate our proposal, we provide examples from the Chilean Climate Risk Atlas case: the analytical framework and methodological pipeline we present here were developed for and tested around this case. This is the first paper illustrating them in an integrated manner. Section 5 presents brief conclusions and policy implications.

2. Urban Resilience: A Brief Literature Review and Key Challenges for an Integrated Framework

As anticipated in Section 1, the concept of resilience—from the Latin *resilio* or "bounce back"—has been gaining growing popularity since the second half of the XX century (Meerow & Newell, 2015) in a variety of scientific domains, each developing its specific understanding and usage of the concept (Olsson et al., 2015; Xue et al., 2018; Thoren, 2014). Although cities are just one of the fields to which the concept has been applied, the attempt to build resilient cities has drawn much attention lately. Early literature on urban resilience goes back to the late 1970s, the literature starts gaining a foothold in the mid-2000s and has been steadily growing ever since, reaching almost 900 yearly publications by 2018. It is also quite a diverse literature with more than 1,000 journals and 12,000 authors involved (averaging almost three authors per paper), coming from more than 3,500 organizations from different countries. Particularly prolific countries include the US, India, Australia, China, and Canada. All leading journals are strongly interdisciplinary, including Sustainability, the International Journal of Risk Reduction, Natural Hazards, and Cities. Likewise, leading research areas are also interdisciplinary, including Environmental Sciences and Environmental Studies, followed by Water Resources, Urban Studies, and Geography.

This literature's sheer size and heterogeneity make a comprehensive review of all existing contributions quite a daunting task. The literature has faced this challenge by making increasing use of computer-assisted analysis to substitute or complement traditional systematic review methodologies, with the double benefit of allowing to embrace larger number and variety of publications and help to avoid subjective biases and to achieve rigorous, timely processing, and examination of key contents (Billi et al., 2021; D'Amato et al., 2017; Schober et al., 2018).

Topic models, in particular, are computer-based statistical tools that perform better than other forms of automated text analysis (Wiedemann, 2013) in their ability to account for the multiple possible meanings of words by calculating latent contexts of linguistic symbols (Jelodar et al., 2017; Steyvers & Griffiths, 2007). Latent Dirichlet Allocation or LDA (Blei, 2012) is the most widespread algorithm offering rich text analysis and relatively straightforward interpretations. In this paper, we generated an LDA topic model of the urban resilience literature, which allowed us to identify and map key topics and approaches tackled in this literature, as well as single out particularly relevant publications that went through a deeper qualitative screening process (for an in-depth description of the methodology used, please check Text S1). A detailed description of the topic model results can be found in Text S3, together with a list of key papers identified in association with each topic.

Through this method, we found that the literature on urban resilience encompasses (References provided in relation to these topics are for illustrative purposes, and refers to some of the most cited papers covering each of the topics. For a more detailed description, please see Supporting Information).

1. **A wide variety of threats to which cities may be exposed.** Urban resilience encompasses the ability of cities to cope and adapt to a variety of specific hazards, such as heat waves (Bobb et al., 2014), flooding (Djordjevic et al., 2011), sea-level rise (Neumann et al., 2015), fires (Fernandes, 2013) or earthquakes (Ainuddin & Routray, 2012), as well as transversal menaces such as climate change and their impacts on cities (Hunt & Watkiss, 2011). Noticeably, while some of these hazards arise from factors and processes

exogenous to the city, others are rather the result of the pathway of development and daily operations characterizing cities.

2. **Several kinds of (urban) systems and services exposed to these threats.** These include, on the one side, impacts on "natural" endowments including availability, quality, and accessibility of water resources (Astaraie-Imani et al., 2012; Ferguson et al., 2013), as well as biodiversity and ecosystem services to urban dwellers (Gomez-Baggethun & Barton, 2013), including urban vegetation (Cook-Patton & Bauerle, 2012); on the other side, human-made artifacts, including energy distribution networks (Kammen & Sunter, 2016), transport systems (Ganin et al., 2017), and various kinds of infrastructures as well as food systems (Barthel et al., 2015). A further segment of the papers refers to urban socio-demographical processes, including human lifestyles, cultures, health care, land-use changes, and migration (Eakin et al., 2010; Wong & Song, 2008).
3. **Multiple pathways driving resilience.** A variety of different variables and strategies are connected to urban resilience, including, on the one hand, physical-technical attributes such as research and employment of advanced materials and robust engineering and architecture to uphold disturbances (Kouroussis et al., 2014; Weerheijm et al., 2009), planning aspects such as resilient network design, smart technologies, or urban design (Karrholmm et al., 2014; Novak & Sullivan, 2014; Ouyang et al., 2012) and on the other, socio-cultural characteristics, such as the importance of social capital, culture, solidarity and shared learning, determinants of resilient economic behavior, and so on (Horowitz, 2013; Jakes & Langer, 2012; Wolf et al., 2010).
4. **Different analytical-methodological perspectives on resilience.** Some papers explicitly strive to measure resilience (Cutter et al., 2010), while others include resilience as one factor amongst others within a wider effort to assess risk and vulnerability in cities (Balica et al., 2012). Similarly, some adopt resilience as a principle in city design or governance (Ahern, 2011; Wardekker et al., 2010) or disaster management (Berke & Campanella, 2006). Others use it to explain how ecosystems, businesses, households, and other relevant entities and processes within cities can persist despite disturbances which may affect them (Jabeen et al., 2010; Martin & Sunley, 2015; Pickett et al., 2004).

The wide variety of threats, systems, factors, and approaches that the literature associates to the concept of urban resilience supports our proposal since it highlights the need for a high-level analytical framework that may help articulate and compare different studies on resilience and inform the construction of integral, complex, and self-adaptive indicators of urban resilience for present and future threats.

Moreover, an in-depth review of the key papers included in each of the relevant topics identified by the model led us to conclude that an integrated framework on climate-sensitive urban resilience should strive to tackle at least six key challenges (see Table 1). We may say that these challenges offer boundary conditions for the integrated framework on urban risk and resilience that we aim to develop in this paper. The table summarizes how our proposal tackles each challenge.

3. Six Analytical Distinctions on Urban Resilience

To address the challenges introduced above, we provide six analytical distinctions, aiming at specifying different elements and processes integrating resilience analysis within climate risk assessment at a city level. While each distinction can be grounded into a very wide corpus of literature (see Text S1), we only quote the most relevant or illustrative scholarly works for each. Please refer to the previous section and the Text S1 for a more in-depth review of existing research. We rely in a particularly extensive way on the socio-ecological scholarship on resilience to build our framework (Biggs et al., 2015; Folke, 2016; Holling, 1973, 2001; Walker & Salt, 2006), which provides a pioneering attempt to link up the concept of resilience with the terminology used by risk and vulnerability assessments (Chapin et al., 2009), hence, offering a deep and sophisticated account on the topic. We also look at parallel advancements that have occurred within other systemic approaches such as the socio-technical transitions perspective (Geels & Kemp, 2007; Geels & Schot, 2007; Hodbod & Adger, 2014; Lawhon & Murphy, 2012) and social systems theory (Luhmann, 1995, 2007; Olsson et al., 2015).

10.1029/2020EF001508

Table 1
Challenges for an Integrated Framework on Urban Resilience, and our Proposed Solutions

Challenge	Description of the challenge	How our framework tackles this challenge (Sections 3 and 4)
Heterogeneity	Embrace multiple kinds of ecological, technical, and socio-cultural entities and processes that make up a city as well as their interactions	We provide a general definition of a system and its resilience compatible with a wide variety of urban functions, encompassing natural endowments, technical artifacts, symbolical-semiotic constructs, as well as their interactions (cf. 3.1)
Multihazard analysis	Consider multiple threats, both endogenous and exogenous to the system, acute, and chronic ones	We adopt a "systemic" definition of resilience, which makes room for a variety of threats and allows them to compound on each other (cf. 3.2)
Multiple timeframes	Distinguish multiple time frames, including climate disturbances considering both short and long-term impacts	We differentiate two main "pathways" to resilience, respectively, linked to the systems' ability to substitute or rearrange its components, or to alter and evolve its structures (cf. 3.3)
Intentional steering	Clarify the interaction between spontaneous, undirected processes shaping up urban systems and an ongoing attempt to direct and steer cities intentionally	We distinguish two kinds of structural evolution (and corresponding pathways to resilience): spontaneous/emergent learning and adaptability, and intentional adaptation (cf. 3.4)
Controversiality	Contrast multiple perspectives on goals and priorities associated with cities and acknowledge potential trade-offs to pursue such goals	We discriminate between positive and negative resilience, and we clarify how the governance of a resilient system should also foster its ability to self-transform and to overcome existing gaps and inequalities (cf. 3.5)
Multiscalarity	Encompass urban systems situated at multiple scales and the corresponding cross-scale interdependencies	We articulate the resilience of constituting systems with the resilience of the city as System-of-Systems (cf. 3.6)

3.1. Delimitation of Resilience: Disturbances and Services

Resilience is an emergent, latent property that cannot be observed directly. However, it can be inferred based on how the system "behaves" in the face of disturbances (Martin-Breen & Anderies, 2011). Unfortunately, the complexity of urban systems means that these tend to shun simple, generalized explanations, and shift in behavior in most unpredictable ways (Midgley, 2003), often lacking stable and recognizable "states or identities" hindering the specification of what is to be taken as a relevant system "behavior." Moreover, their boundaries are not always clear, so that distinguishing a system from its environment often involves contingent or even arbitrary decisions (Olsson et al., 2015; Smith & Stirling, 2010; Vale, 2014).

To overcome these challenges, we adopt a broad definition of resilience as the structural ability of a complex adaptive system—i.e., a system composed of a variety of elements coupled between one another with emergent properties and at least with some degree of self-organization (Folke et al., 2005; Norberg & Cumming, 2008; Urquiza & Cadenas, 2015)—to maintain a given level of performance or "service" despite the disturbances affecting its key components (Figure 1).

Focusing resilience analysis on the maintenance of "services" helps to make resilience observable since services can be often measured, either directly or by proxy. By the same token, focusing resilience on services helps to define the boundaries of the analysis. While each system may have an infinity of potential components, only components playing a major role in the provision of the specified service will need to be tackled in the analysis. How many and which ones will depend on the complexity of the service and the degree of precision required by the analysis, suggesting a multitiered approach to resilience analysis (Linkov et al., 2018).

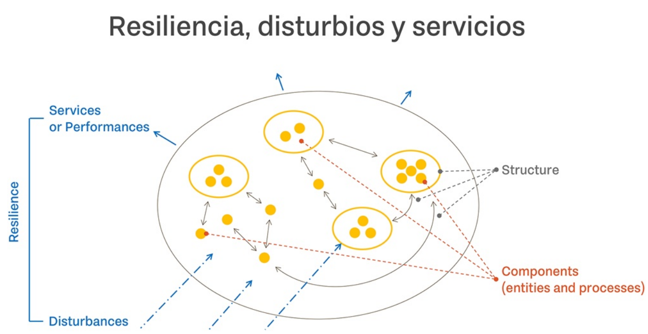

Figure 1. Definition of a system and its resilience expressing the maintenance of service despite disturbances affecting its components.

Our definition is compatible with a wide variety of systems and services whose components may refer to natural endowments, technical artifacts, or symbolical-semiotic constructs. Existing approaches to urban resilience such as the ones advanced by the Rockefeller Foundations' 100 Resilient Cities or by ONU-Habitat's New Urban Agenda differentiate various possible "urban services," but there is still a lack of a standardized classification of these services. We propose to distinguish:

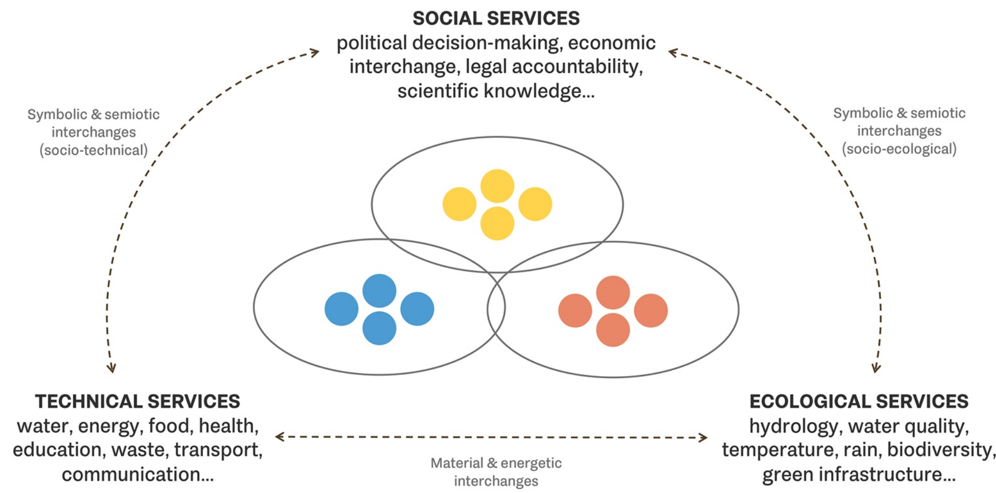

Figure 2. Types of urban services and their relationships.

- *Ecological services* explicitly linking with the literature on ecosystem services (Bennett & Garry, 2009; Chapin et al., 2010; Gomez-Baggethun & Barton, 2013) and including the provision of essential elements to support their health and lifestyle, the regulation of their environment (e.g., temperature or air quality) and supporting services necessary for the expected functioning of other key urban systems
- *Technical services* that, as socio-ecological services, depend on interchanging matter and energy but are governed by a combination of technological artifacts and socio-economic structures of innovation, transformation, and coordination (Geels & Kemp, 2007). For instance, these include the provision of energy, drinkable water, transport and telecommunication, education, health care, and others
- *Social services*, encompassing high-level symbolic and semantic structures ensuring the possibility for meaningful communication and interchanging information and expectations, coordinating social action within and about cities (Luhmann, 1997b; Urquiza & Cadenas, 2015). Examples of these services are: legitimate political processes and institutions to assign power and make (or criticize) collectively binding decisions; reliable scientific procedures to generate, review and spread evidence; functional markets and currencies to ensure the financing, production, allocation, and distribution of scarce goods and services; enforceable laws and juridical systems to uphold and guarantee societal norms and normative principles; shared cultural values and practices, to shape and select knowledge, behaviors, interactions, and others of the like

Figure 2 summarizes these services, along with the relevant material, socio-ecological and socio-technical interchanges linking one domain to the other.

3.2. Scope of Resilience: Specific Components and Generic Structures

An old debate dividing complex systems scholars is whether the analysis should focus on the system response to individual threats and disturbances or rather on the whole array of possible and actual disturbances on which the system may incur. These two different approaches have been sometimes labeled as "specific" versus "generic" resilience (Miller et al., 2010) or rather, "inherent" versus "adaptive" resilience (Cutter et al., 2008) or even "local" or "global" resilience (Thoren, 2014). Researchers from different fields have linked excessive stress on individual-threat resilience with a reduction in multithreat resilience: while the former may allow the system a higher control in countering the effects of ordinary variations in the environment upon its behavior, it would also imply a decreased flexibility and response capability in the face of unexpected disturbances overcoming the tolerance threshold of the system with potentially catastrophic effects (Holling, 2001; Perrow, 1984; Pickett et al., 2013). Likewise, some have argued that what the resilience approach brings to the table of risk assessment is precisely a systemic perspective concerning multiple threats at once (Linkov & Trump, 2019). Nevertheless, both interpretations remain of current usage in different strands of literature on resilience in general and urban resilience particularly (Meerow et al., 2016).

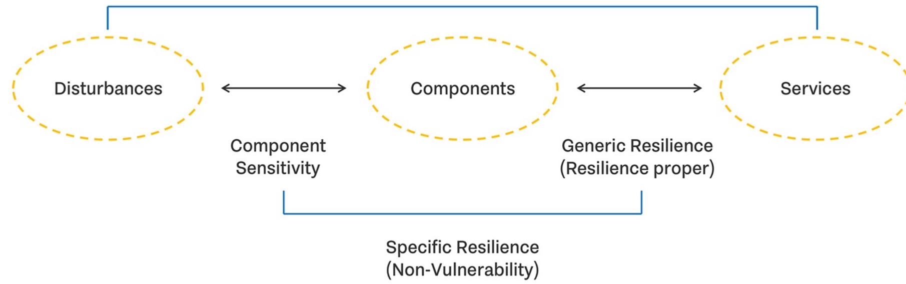

Figure 3. Scope of resilience: sensitivity, generic resilience, and specific resilience (nonvulnerability).

Our framework strives to provide a coherent and fully systemic take on resilience by acknowledging the need to distinguish generic and specific resilience while also retaining both as useful analytical dimensions in the context of risk assessment. We decompose the observed impact of disturbances on the services provided by a system into two parts (Figure 3): on the one hand, the effect that the disturbance implies for the system-specific components such as specific goods, processes, individuals, infrastructures, and the like; on the other hand, the overall response of the system (and the service it provides) to affectations suffered by some of its components. Drawing on IPCC's framework on climate vulnerability (Abram et al., 2019; IPCC, 2014), we may call the first factor "sensitivity" of a component to a given hazard. In our framework, this measures the inherent propensity of a given component to be "disturbed" by the hazard. For instance, the increase in extreme weather events could potentially affect both the demand and supply of a particular urban service, such as electricity supply: power plants, transformers, electrical lines, appliances, or user preferences, to name a few. Each of these infrastructures may be more or less "sensitive" to any given hazard: a hydrological power plant will suffer more from drought than a coal-based one, and underground electrical lines will not be so easily affected by a storm as surface ones.

However, the service's overall vulnerability service is not limited to the sum of these sensitivities; rather, it also encompasses the system's overall predisposition to uphold disturbances in its components and self-organize itself despite—or even, in the face of—these disturbances (generic or "systemic" resilience). Different from "sensitivity," generic resilience is a genuinely structural feature of a system, not reducible to the behavior of its specific components: this is another way to phrase the famous maxim that "a system is more than the sum of its parts." For instance, a monitoring and early warning system, able to encompass several hazards at once that may affect the energy system, may be an example of generic resilience.

This proposal clarifies the relationship between vulnerability and resilience. While in early approaches (e.g., Holling, 2001), resilience was often understood as equivalent to the lack of vulnerability (an idea which would imply the redundancy and thus analytical uselessness of either of the terms), more recent reflections have pointed out that systems can often be both resilient and vulnerable or neither resilient nor vulnerable (for a discussion see: Miller et al., 2010; Urquiza & Cadenas, 2015). Thus, a system can be resilient and vulnerable when all or most of its components are sensitive to the relevant climate threats they are exposed to but, at the same time, the structure of the system is strongly able to compensate for such sensitivities. On the contrary, a system should be considered nonvulnerable and nonresilient at the same time, when it features a very low structural ability to undergo disturbances but—at least for the time being—is not sensitive to any of the climate threats it may become exposed to.

As a plus, limiting the scope of resilience proper (generic resilience) to the structural dimension ensures analytical comparability through time: as a structural-level property, resilience will not depend on specific changes that may have incurred in particular components or on the configuration of such components. Moreover, defining resilience at a structural level allows to take full advantage of adopting a system perspective in that structural attributes that have been shown to increase resilience within one given domain—or at a given scale—can be employed to predict resilience within another domain—or scale (Holling, 2001).

Finally, this definition of resilience makes room for a wide variety of threats: what matters for resilience analysis, in fact, is not the threat itself nor even the amount of the disturbance it causes on one or more of

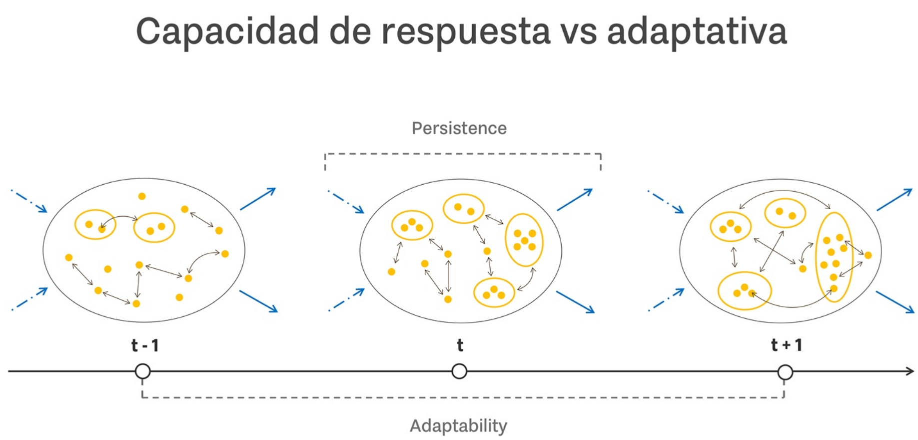

Figure 4. Resilience timeframes: flexibility (persistence) and adaptability.

the key components required for the provision of a given service but rather how much the system is able to withstand such disturbance without significantly altering its level of service.

3.3. Timeframes of Resilience: Persistence Versus Evolution

The existing scholarship also offers two different interpretations about what is to be understood as a "resilient" behavior for a system. A part of the literature reads it in terms of "bouncing back"—paralleling the etymological root of the term-stressing that resilience implies the maintenance or recovering of some sort of equilibrium upon a disturbance (Alexander, 2013). Other interpretations, however, link resilience to the existence of multiple equilibria or "basins of attraction" and to the propensity of a system to shift from one to the other when faced with a disturbance large enough to overcome its critical thresholds (Chapin et al., 2009; Folke, 2016; Scheffer et al., 2002; Sietz & Feola, 2016). Since the second understanding was first made popular within the ecological literature, it is sometimes dubbed as "ecological" resilience, in opposition to "engineering" resilience (Holling, 1996), or "persistence" versus "adaptability" (Walker et al., 2004), or "adaptability" and "agility" versus "robustness" and "resistance" (Galaitsi et al., 2020). To be sure, this distinction was already well known within second-order cybernetics (on which most systems-theoretical approaches ground themselves), distinguishing between "trivial" systems, whose performance is a function of the structure of the system and of inputs (in our case, the disturbance it suffers); and nontrivial, complex systems, whose structures are constantly evolving as a result of their own operations (von Foerster, 1981).

Hence, there is a need to distinguish two kinds of resilience according to the timeframe adopted by the analysis (Figure 4). When we focus on the short term, we are mostly interested in the ability of the system to rearrange its components or substitute one component for another in order to maintain the given level of service without significantly altering its structure. For instance, referring to the example introduced above, the resilience of electrical supply may be higher when the system counts with significantly more installed capacity than peak demand as well as with multiple and networked distribution pathways when it is able to shift quickly and seamlessly from one source to the other or from one distribution pathway to another and so on. This kind of short-term focus on resilience, hereafter dubbed "flexibility" (or "persistence"), can be contrasted with a longer-term view, observing the ability of the system of maintaining the level of service in the face of a changing environment by ways of evolving its structures, which we will subsequently call "learning" (Desouza & Flanery, 2013; Urquiza & Billi, 2018; Walker et al., 2004). The latter is particularly important in a context of uncertainty with respect to the possible nature and outcome of risks facing a system, and particularly for proactive management of potential but unknown risks of the future (Linkov & Trump, 2019).

Noticeably, while the concept of "flexibility" can apply to all kinds of systems, including both trivial or noncomplex systems (such as inanimate artifacts) and complex or nontrivial systems (such as social, technical, and ecological systems), "learning" is only proper for complex, adaptive systems. When reaching a given threshold, trivial systems simply "break down" when they overcome their resilience threshold, and when this happens, their functionality is irremediably lost or maimed. Conversely, when complex, nontrivial systems are pushed beyond their critical threshold, they shift to a new regime of stability, which, depending on the case, may present a higher or lower level of service than the one they left (Folke, 2016; Holling, 2001; Linkov & Trump, 2019). For instance, enduring exposure to a disturbance in electrical supply may push the entry of newer and more reliable technologies, the building of additional power plants, or the adoption of user practices aiming to limit the effect of the disturbance, e.g., buying power generators, storage systems, or even appliances not relying on electricity (such as wood stoves for cooking and heating, for instance).

Lately, a third alternative has been introduced implying the complete absence of balance, thus, imbuing resilience with a mainly metaphorical meaning as stressing the need to generate forms of planning and governance apt for the ever-changing and constantly unstable nature of the modern world (Eraydin & Tasan-Kok, 2013; Pickett et al., 2004). In our framework, this notion of resilience can only be understood by moving on to an additional distinction encompassing the degree of "directionality" or "intentionality" of resilience.

3.4. Intentionality of Resilience: Memory and Learning Versus Self-Transformation and Governance

Adaptability has to do with the evolution of the structures of the system. Systems-theoretical approaches mostly agree on the fact that the most frequent form of evolution takes the form of an undirected process of "morphogenesis": the evolutionary trajectory of a complex and nontrivial system is not correctly described by thinking in linear terms as an ordered and gradual advancement toward a rational and predictable telos. On the contrary, systemic structures are best seen as a highly unlikely and contingent outcome, as the emergent product of the interaction between semirandom variations and structural selection (Luhmann, 1984, 1995; Maturana & Varela, 1987), innovation and socio-technical regimes niches (Voβ et al., 2009) or creative renewal and system control (Gunderson & Holling, 2002). Were it not for the prevalence of semirandom processes and the chances of experimentation and variety these bring forth, the evolution of ecosystems, technologies, and societies would have been much slower than has been the case (Luhmann, 1997b). We will label these emergent processes of systemic evolution as the "memory/learning" dimension of resilience.

On the other hand, these considerations do not completely preclude the possibility that a system is intentionally steered or "governed" toward a desirable outcome. One of the peculiar features of "social" systems (as opposed to ecological or technical ones) is precisely their constant concern for "planning ahead," i.e., attempting to put up mechanisms pursuing the permanence of the system and the services it delivers in the face of known, foreseeable and even speculative disturbances that may be of interest in the future (Linkov & Trump, 2019; Westley et al., 2002). We may call this dimension of resilience "governance" or "self-transformation."

The nonlinear self-organized dynamics of complex systems make such governance a particularly daunting task, especially since any intervention in the trajectory of a complex system unavoidably becomes part of the system it is trying to steer (Beck, 2006; Voss et al., 2009). The literature offers different ways to make governance efforts more "reflexive," e.g., to ensure they look at themselves as part of the change they aim to enact imaginaries. Visions and semantics seem to play a major role in this sense: they allow to create a—momentary—distance between the planner and the system to be directed and single out aspects of the behavior of the system which are to be controlled and monitored (Konrad, 2010; Luhmann, 1997a; Rip, 2012). The same may be said for deliberative spaces and polycentric arrangements (Pahl-Wostl et al., 2012; Urquiza et al., 2019c; Willke, 2006), which by confronting different perspectives on a problem may help overcome possible blind spots of each singular standpoint.

Flexibility and, to an extent, "memory/learning" is essentially a "reactive" mechanism responding to disturbances if and when these come to occur. As such, it may be blind to the consequences that a present response of a system may deliver on the emergence of future hazards affecting the very system or different services within the city. For instance, technologies based on fossil fuel exploitation may be less prone to suffer climate-related disturbances than cleaner sources such as solar and wind power. However, they may also cause further strain on local social-ecological systems while increasing at the same time the future climate

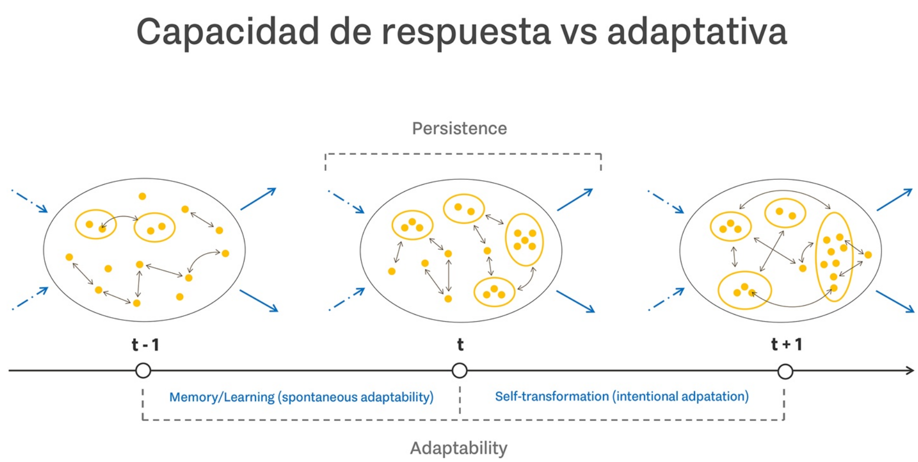

Figure 5. Intentionality of resilience: learning from Figure 5 is decomposed into "memory/learning" (unintentional/undirected/spontaneous adaptability) and "self-transformation" (intentional/directed/governance-mediated adaptation).

hazards the system will have to face. Similarly, when households switch to wood or petrol-based alternatives for home heating and cooking, they may be making themselves more resilient in the face of erratic electrical supply. Nonetheless, they are also decreasing their resilience in the face of resources dwindling stocks while also possibly contributing to hamper other urban services such as clean air (due to indoor and outdoor pollution caused by such technologies) or biodiversity (due to the potential incentives for forest overexploitation).

On the contrary, "self-transformation" aims to take full charge of these secondary effects and the trade-offs they may entail. Thus, it is a strongly intentional and directed mechanism contrasting the "unintentional" and "emerging" character of reactive resilience (Figure 5). Continuing with the previous example, such resilience will be achieved by promoting an integral and long-term energy transition balancing both short-term impacts on electrical supply resilience and long-term consequences both on the energy sector and other key urban services.

3.5. Normativity of Resilience: Adaptive Governance Versus Transformative Governance

While part of the literature depicts resilience as a constitutively positive and desirable property (Meerow et al., 2016; Olsson et al., 2015), a growing number of scholars have noted that resilience implies trade-offs between territories, scales, populations, or perspectives. What may mean resilience for some populations, territories, or systems can be a source of disturbance and risk for others (Hahn & Nykvist, 2017; Hodge, 2013). Accordingly, many scholars have stressed the unavoidably political and ethically laden character of resilience analysis and practice (Barnes et al., 2017; Chaffin et al., 2014; DeCaro et al., 2017; Hahn & Nykvist, 2017), demanding in turn for more participatory, distributed, and accountable forms of decision-making and social organization (Barnes et al., 2017; DeCaro et al., 2017), among other things, to define what ought to be preserved and what ought to be changed.

Particularly, in a significant number of cases, "resilience" can be characterized as a "negative" (or undesirable) attribute instead of a positive and desirable one. For instance, mitigating global GHG emissions may require urban systems to engage in a full-scale energy transition, which could also serve as a way to increase the availability of high-quality, reliable energy sources for all the population and to reduce indoor and outdoor pollution within the city. However, when attempting to put in place such a transition, decision-makers are likely to find out that the existing system puts up a strong resistance to change: economic expectations, socio-technical artifacts, and even socio-cultural norms have adapted to a certain structural configuration and, in so doing, they are constantly maintaining and reproducing such configuration. Moreover, they might realize that some transition options are closed up altogether because they lack prerequisite assets or conditions that past policies have been unable or unwilling to provide.

These forces of "lock-in" and "path-dependency" (Geels, 2012) tend to limit the degree to which complex systems can be steered away from their current pathways. They may therefore be considered a form of "resilience," whereas the attempt to induce a sustainable transformation is processed by the very system as a hazard rather than as an opportunity. When this is the case, resilience analysis can help to depict the factors that are hindering the transformation of the system and devise ways to overcome it (Chaffin et al., 2016).

A similar argument can be made about poverty and inequality: a system may be perfectly resilient while also stuck in a low-performing equilibrium (sometimes tagged as "poverty trap" in the literature). When this happens, the services it offers are suboptimal, but the system's inertia (or resilience) prevents it from transitioning to a higher (and more collectively desirable) equilibrium (Carpenter & Brock, 2008).

The literature talks about adaptability—and transformability—oriented resilience research to capture this distinction (Folke, 2016; Walker et al., 2004) and of adaptive and transformative approaches to resilience governance (Chaffin & Gunderson, 2016; Chaffin et al., 2016): whereas the former stresses actions sustaining current trajectories or pathways, the latter implies shifting pathways or creating new ones. This adds a temporal trade-off to resilience where the system's current stability is opposed to its future sustainability, thus linking resilience analysis to transformation and transition studies (Feola, 2015; O'Brien, 2012).

Our framework combines both adaptive and transformative approaches by separating (albeit, only analytically) resilience assessment focusing on system structures from the normative appraisal of its desirability, which depends on the choice of the services used as a reference for the analysis. In other words, one thing is to identify the determinants of resilience and assess how resilient is a system; another is judging whether this resilience is "positive" or "negative" and thus, whether to engage in adaptive governance trying to foster it or in transformative governance in an attempt to "overcome" it. This distinction makes the delimitation and prioritization of urban services into a key step in the analysis: a step that cannot be performed aseptically but instead requires a deep engagement of the research team, the decision-makers, and the community. Our framework encompasses both scenarios, aiming at being intelligible both for risk management communities interested mainly in the adaptability dimension and to scholars and practitioners of sustainable transitions and transformation who have been mostly concerned with the second scenario where the system's ability to resist change (its resilience in other words) is precisely what must be fought.

3.6. Scale of Resilience: Autonomy of Constitutive Systems and Coherence of the System-of-Systems

While stressing the difference between adaptive and transformative governance of resilience, the literature also acknowledges that both approaches require a deep understanding of the trajectories and interdependencies of systems at multiple scales and across scales (Gunderson et al., 2017; Linkov et al., 2018; Liu et al., 2017).

This consideration becomes especially relevant in the case of a city. Cities are not simply a system but a System-of-Systems or SoS (Ernstson et al., 2010): a system with emergent characteristics and dynamics whose constitutive subsystems are, at least partly, independent one from the other so that the "normal" performance of each of them can constantly become a cause of stress or disturbance for the others (Cavalcante et al., 2016). While each constitutive system is semi-independent, they interact by sharing components or services, thus generating reciprocal disturbances. These, in turn, constitute a constant threat for both systems but may simultaneously represent an opportunity for learning and evolving. We postulate that aside from specific entities and processes—and to include this important facet within our framework—, components may also be systems themselves: the latter in turn may be composed of further entities or processes and feature their own resilience. In this fashion, the ability of a System-of-Systems to maintain a given level of service will depend: (a) on the disturbances affecting components of constituting systems; (b) on the resilience of each constitutive systems in respect to the disturbances affecting them; and (c) on the resilience of the System-of-Systems in respect to varying level of services on the part of the constitutive systems (acting as components for the System-of-Systems).

As such, at the System-of-Systems level, resilience cannot be achieved simply through flexibility or emergent learning. It rather always requires adequate governance able to balance two competing—and both complementing-principles of coherence and autonomy (Cosens et al., 2018; Vaas et al., 2017; Willke, 2016):

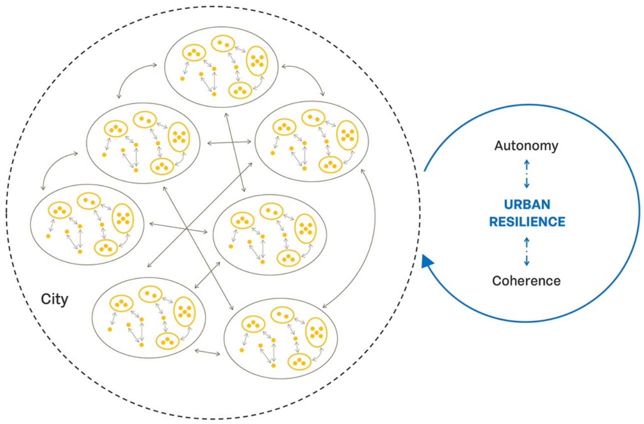

Figure 6. Resilience of a city as a System-of-Systems.

on the one hand, it must grant each of the constitutive systems the autonomy required to enjoy flexibility-based and learning-based resilience. On the other hand, it must ensure that the System-of-Systems enjoys a high enough level of coherence and coordination so that the efforts undertaken by one of its constitutive systems to foster its resilience do not turn into an additional source of disturbance for other constitutive systems (Figure 6).

Socio-ecological systems literature shows that within sustainable ecosystems, these opposing principles of autonomy and coherence are reconciled by a "panarchical" arrangement where subsystems and constitutive systems at different scales are organized in a hierarchical and nidified fashion. Therefore, while each scale follows a highly autonomous cycle of adaptation and self-renewal, emergent innovation and stabilization processes can operate across scales (Allen et al., 2014; Gotts, 2007; Gunderson & Holling, 2002). While these insights were originally developed for ecosystems and biological life forms, they have been gradually extended to consider systems originating from the coupling between social and ecological dynamics (Garmestani et al., 2009).

Similar results can be achieved in terms of governance by adopting arrangements such as the polycentric one proposed by Nobel-prize Elinor Ostrom (Ostrom, 1990, 2009). This model fosters acknowledging high degrees of operational autonomy to each distinct scale of a political system allowing for independent decision-making, knowledge creation, and experimentation coupled with continuous feedback systems across scales. Accordingly, negative results would be prevented from cascading while positive ones may be efficiently transferred among scales generating more efficient learning, flexibility, and resilience to changes for the whole system. Moreover, it promotes self-organization, coordination, trust, and shared learning at multiple scales (Prieto Barboza, 2013). By this token, the model lays the foundation for a form of adaptive environmental governance able to combine efficient exploitation of the system potentials (in terms of critical functionality) with a continuous exploration of alternative structural configurations (Duit & Galaz, 2008). This feature is extremely relevant, especially in systems facing a high degree of uncertainty and approaching a potential threshold or regime shift (Cosens et al., 2018; Poteete et al., 2010; Urquiza et al., 2019a, 2019b; Vaas et al., 2017).

4. An Analytical Framework and Methodological Pipeline to Integrate Resilience in Urban Risk Assessment

Based on the insights discussed in Section 3, we provide an integrated analytical framework clarifying how the six analytical distinctions illustrated above link up with different determinants of climate-related urban risk and with the three resilience dimensions we identified (Figure 7).

The framework is explicitly designed to maximize integration within existing approaches and particularly to articulate with IPCC's climate risk and vulnerability framework (top part of Figure 7), with the relevant difference that we explicitly restrict the analysis to the maintenance of a user-defined set of "services" acting as empirical (and normative) reference for risk assessment. Following IPCC, we understand risk as being made up of a combination of hazard (defined as an event or process external to the system potentially triggering disturbances into the latter), exposure (identified as the presence within the system of components potentially affected by said hazard) and vulnerability, i.e., the predisposition of the system to see its services affected by hazards to which its components are exposed (1). As in IPCC, we decompose vulnerability into sensitivity operating at the level of individual components and resilience proper acting at a more systemic/structural level (2). Resilience itself encompasses both reactive Coping Capacity and proactive Adaptive Capacity, thus, linking up with the terminology used by the climate adaptation community (4). However, as specified by our proposal, Coping Capacity requires both Flexibility, focused on the short-term ability of the system to maintain the service despite the disturbances affecting its components, and memory/learning, manifested in the degree to which the system has learned from past impacts (3). Memory and learning are

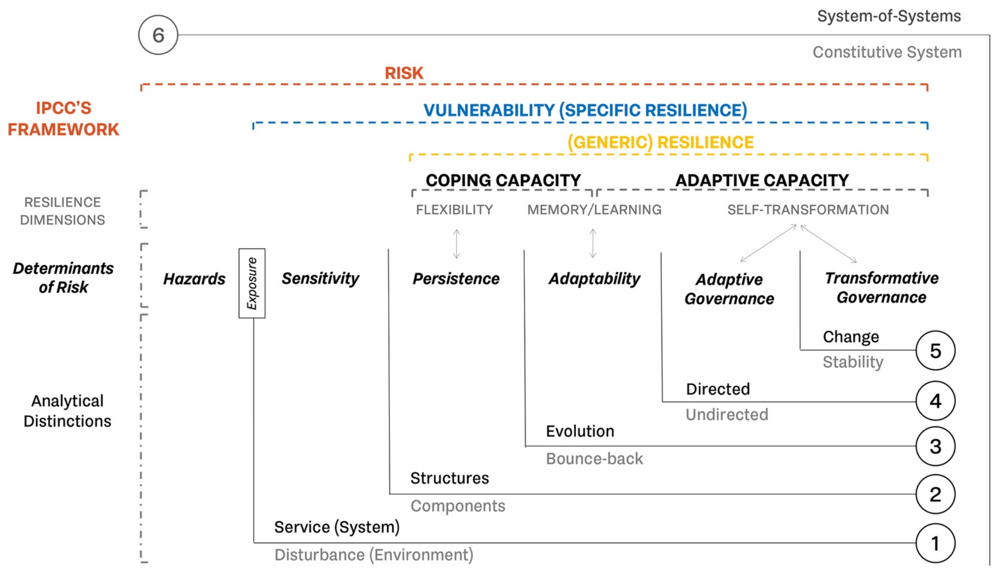

Figure 7. Reading from the bottom upwards: analytical distinctions discussed in the previous section (bottom), determinants of risk derived from said distinctions (lower middle), key dimensions of resilience making up our proposal (upper middle), and analytical axes of Intergovernmental Panel on Climate Change (IPCC)'s framework (top). The analytical distinctions are numbered accordingly to the order in which they appear in Section 3.

also essential to Adaptive Capacity. However, this also requires the ability of the system to self-transform, i.e., governance. The latter can, in turn, be decomposed in Adaptive and Transformative Governance according to whether it is oriented to stabilize or change the existing configuration of the system and the degree and distribution of the services it provides. This depends on whether resilience is judged as a positive or a negative attribute in the case at hand (5). Finally, all this is inscribed within a nidified understanding of the city as a System-of-Systems (6).

Building on this framework, we further advance a methodological pipeline to streamline the application of urban resilience in the context of climate risk assessment (Figure 8). The aim is to line up a workflow that may guide researchers and practitioners in describing the overall risk sustained by a city in the face of multiple climate-related threats at once by explicitly considering: (i) the disturbances potentially sustained by the individual components of each system constituting the city; (ii) the resilience of each of these systems against such disturbances; and (iii) the city resilience as a whole. In turn, this can serve to inform decision-makers about the best approach to minimize climate risk either by acting on individual components or by governing resilience. Notice that the steps described in the workflow can be tackled with different techniques and varying levels of depth and complexity depending on the purposes of the analysis. This parallels the idea that risk assessment is a multitiered challenge, requiring increasingly sophisticated techniques and approaches the more uncertainty and saliency of the possible impacts and management decisions to me made (Linkov et al., 2018).

To illustrate the usefulness and application of our proposal, we will briefly exemplify its application as part of the work involved in creating the Chilean Climate Risk Atlas (for more information, please refer to the website https://arclim.mma.gob.cl/). The project, which was sponsored by the Chilean Ministry of Environment and involved interdisciplinary research teams from multiple Chilean Universities and led by the Center for Climate and Resilience Research and the Center on Global Change, pursued the overarching goal to create an integrated platform to assess and compare climate change-related risks affecting different economic sectors, territories, and population across Chile. To that aim, the project adopted IPCC's latest definition—plus the methodological guidelines set up by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ, 2016, 2017) to create "impact chains" describing how specific threats can turn into impacts when encountering preexisting conditions of exposure and vulnerability. Our team focused on advancing a characterization of how the specific conditions of each territory, population, and local institutions, may increase or decrease human settlements' vulnerability and their dwellers to several such hazards.

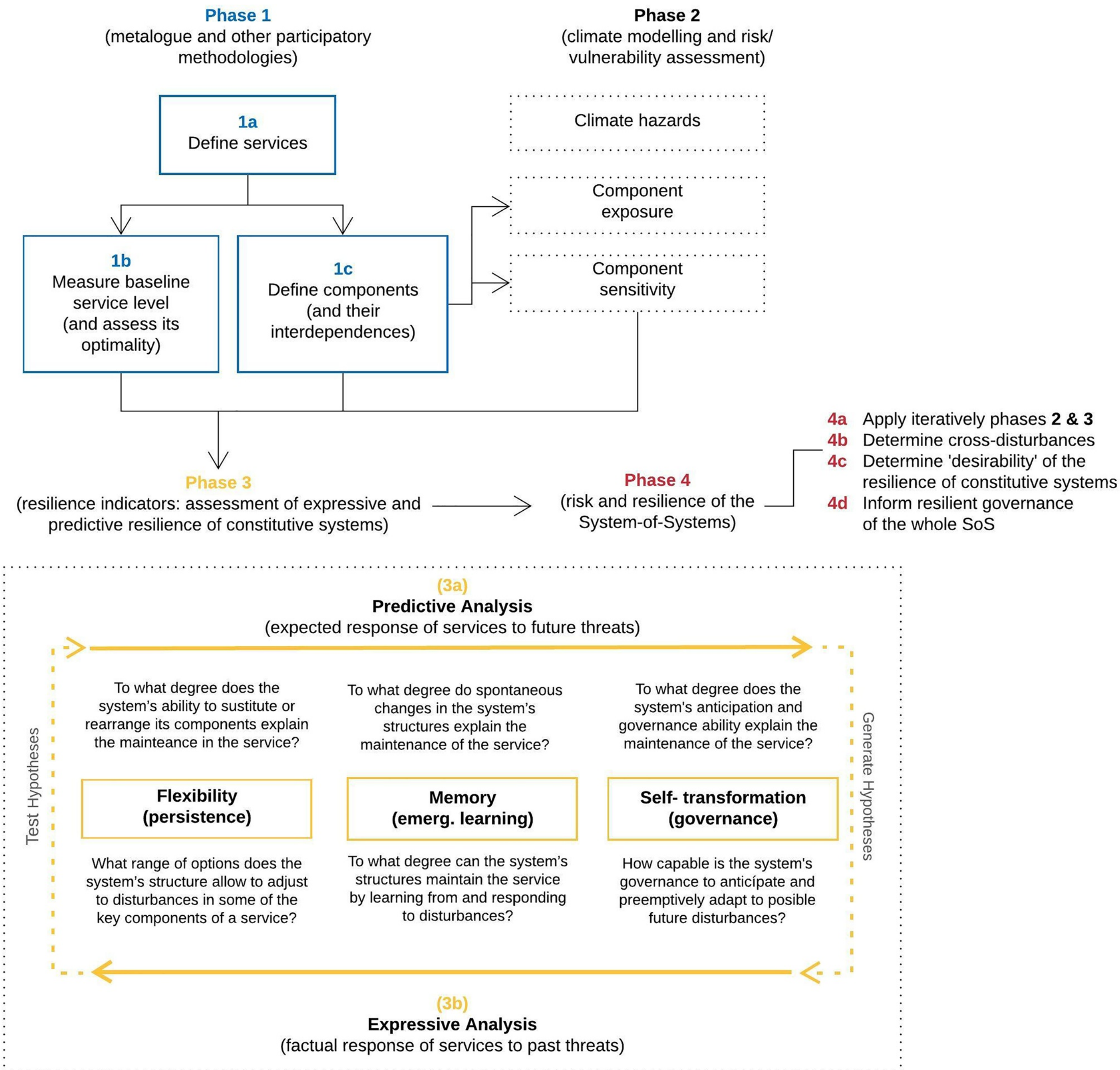

Figure 8. Methodological pipeline to streamline urban resilience within climate risk assessment.

We thus included both key factors increasing sensitivity to each threat and cross-cutting drivers of the ability of each territory and its population to cope or adapt to such hazards, in other words, of their resilience. Moreover, we were chiefly interested to understand how multiple risks interact within a given settlement and how these interactions could increase or decrease risks. For this, we took the study case of the Viña del Mar/Valparaiso conurbation, one of the major urban settlements situated in the country's central coastline.

As displayed in Figure 8, the pipeline is composed of three main phases.

Phase 1 starts by defining services acting as a reference for the analysis (1a): as explained above, services illustrate what is at stake. They represent that which endures a risk and that which must be made resilient. In our case study, these services encompassed water, energy and food security, road and telecommunication connectivity, economic production and livelihoods, and physical and mental health.

Once the services have been defined, the analysis will need to perform a baseline measurement of the level of each of these services so that it may serve as a contrast to observe changes brought about by a disturbance (1b). Depending on the analysis' time horizon, this baseline may refer to predisturbance service level (in case the analysis focuses on a past event) or that which is expected to exist when the disturbance occurs.

This step is also useful to determine whether this level (or distribution) of service is to be considered optimal (and thus, desirable) or suboptimal: in the latter case it may be that the system is stuck in a low equilibrium, making resilience in a negative/undesirable property, instead of a positive one: the goal of the subsequent analysis, in this case, would be expected to focus on transformability more than on adaptability, i.e., it should not only assess pathways to keep the level of service but also to actively improve it (cf. Section 3.5).

Noticeably, suboptimality may be defined in several ways related to the "average" level of service or how it is distributed in different segments of the population. For instance, a city displaying a very high average energy supply for the rich, together with enduring sacks of energy poverty, may be considered suboptimal. Thus, it would present a "gap" in terms of service security, even in the absence of any relevant risk. This situation was often evident in our case study: while Chile is usually considered a "developed" country (UNDP, 2019), it features significant gaps and inequalities in terms of environmental quality, life expectancy, housing quality, and access to infrastructure and essential services, to name a few (Cabieses et al., 2015; Fernández & Wu, 2016; OECD, 2016; RedPE, 2019; Tejada, 2016), which tend to be difficult to change since they are deeply embedded in the socio-economic and political-economic configuration of the country (Huneeus et al., 2018).

A third step (1c) requires decomposing the service into the individual components key for its provision and consumption. Noticeably, different services provided by the same system (for instance, different kinds of energy, different kinds of water use, different road infrastructures) as well as services provided by different systems (e.g., between water, energy, and food systems, between road and communication infrastructure etc.) can share some components: when this occurs, the services and systems can be said to be interdependent in the sense that disturbances affecting one of them will also affect the others. These interdependencies imply a variety of consequences that should be taken into consideration in risk assessment. For example, there may be cascading effects—when the disturbance upon one service potentially affects key components of another service (GIZ, 2018) or competency among multiple services upon key components or inputs (Meza et al., 2015). Likewise, mal-adaptations can occur when an attempt to increase the resilience of one service in the face of a threat results in a loss of resilience in the face of other treats or on the part of other services (Mahmood et al., 2017; Salmond et al., 2016; Zölch et al., 2016). The literature sometimes refers to these kinds of interdependences as "urban nexus" (United Nations, 2019b). In our case study, we reviewed the relevant literature to create a map of the "urban nexus" in the Viña del Mar/Valparaiso conurbation. This map linked up multiple hazards (flooding, sea rise, droughts, heatwaves, earthquakes, and tsunamis) and impacts on services (such as food and water insecurity, economic crises, mortality, and morbidity), together with corresponding factors driving exposure, vulnerability, or resilience, while also clarifying how these reinforce or interact with each other.

The three steps detailed above can be defined as postnormal problems implying epistemic and value uncertainty (Dankel et al., 2017; Funtowicz & Ravetz, 2003). Therefore, they require a process of knowledge coconstruction encompassing different kinds of technical-scientific, political-administrative, and stakeholder perspectives. Transdisciplinary methodologies, such as metalogues (Urquiza et al., 2018) can promote a reflexive and participatory coconstruction of one shared understanding of urban services and components, which may later foster collaboration around its governance, as well as increase collective Futures Literacy in terms of sustainability, resilience, and adaptation (UNESCO, 2019). Our case study engaged relevant stakeholders from the upstart by performing more than 50 interviews with experts from different institutions and sectors. Moreover, we set up a dialogical process with the Planning Department (SECPLA) of the two municipalities, as well as with the Regional Council on Climate Change (CORECC), to jointly define the services we would tackle, the state of these services in both cities, their key components and interdependences.

Phase 2 includes tasks usually associated with urban risk assessment: modeling and forecasting potential climate hazards and mapping exposures and sensitivities to these hazards within the city. Usual methodological pipelines may be used (e.g., GIZ, 2017). The only significant difference introduced by our framework is that exposure and sensitivity do not apply directly to individuals or communities but the key system components identified in Step 1. Therefore, the analysis will need to assess to which degree the key components required for providing a given service are potentially exposed to a threat and how likely it is that they will become "disturbed" by hazards to which they are exposed. In practice, this step involved creating "impact chains" for each combination among the services identified in Step 1 and the relevant threats that may impact these services, identifying key elements influencing each service's exposure and sensitivity to these threats across both cities. Again, these impact chains were built considering both the relevant literature and local experts and practitioners, engaged through interviews and focus groups.

Phase 3 constitutes the actual resilience analysis, which can be performed from two different perspectives: "expressive" and "predictive" (Urquiza & Billi, 2018). In the former case, the analysis focuses on the system's proven ability to maintain its degree of service during past situations. In the second, the assessment aims to forecast—with a given degree of confidence—the future ability of the system to withstand disturbances either known, likely, or hypothesized. Eventually, the latter may serve to guide interventions to increase such ability. Expressive and predictive analyses are meant to feedback each other: resilience predictions will be made based on past evidence from both the target systems and other domains and will be later tested through expressive analysis of upcoming impacts. Noticeably, because of the time frame at our disposal and the lack of robust and easily accessible information on past impacts, in our case study, we limited ourselves to the "predictive" component of the analysis, although it will be important to check the robustness of the predictive hypothesis in future phases of the study.

Both analyses are articulated along the three resilience dimensions: flexibility (persistence), memory and learning, and self-transformation (governance). However, it may be preferable that these three dimensions are tackled in a different order depending on the perspective. Predictive analysis (3a) is most easily performed by starting from flexibility and then moving up to learning and governance measures. On the contrary, expressive analysis (3b) may be best served by progressive exclusion. The analyst may start assessing to what degree the service's maintenance despite past disturbance can be explained by the anticipation and self-transformation capability of the system. It may then move on to assessing the effect of spontaneous adaptations taken up by the system through time. After ruling out the first two alternatives, the specific impact of flexibility on overall system resilience can be identified.

Figure 8 provides specific questions to guide the expressive and predictive analysis of each dimension. Noticeably, these questions can also help identify and categorize some of the key attributes that the literature has associated with resilience. Hopefully, this can also aid in reducing existing terminological heterogeneity.

Based on this same approach, we classified some of the most recurrent attributes that have been associated with resilience in the literature (Table 2). We provide a list of attributes for each dimension, each associated to a brief justification and examples of variables and indicators together with relevant literature supporting them (for information about the methodology employed in bulding such table, see Text S2). In the Chilean case, we were able to map many of these attributes to publicly available variables, including socio-economic and socio-demographic indicators, socio-ecological diversity and degradation, coverage and accessibility of infrastructure and services, institutional and decision-making processes, or the existence of contingency plans. In other attributes, we identified gaps in knowledge that may be supplemented in the future through *ad hoc* surveys or other studies.

Finally, Phase 4 requires combining these results into an analysis of the overall risk faced by the System-of-Systems. As explained above, in this level of analysis, each of the city's constitutive systems may be read as a "component" for the city's overall ability to provide services for the well-being of residents. It is necessary to consider the impact of several hazards on multiple services (and systems) to do this simultaneously. For example, let us consider an imaginary city with three systems, each providing two services. The surrounding ecosystem provides clean water and supplies power for hydropower. The electrical system provides energy for domestic usage and local industries. The industrial market sustains livelihoods but also provides resources to govern ecosystems and maintain/improve electrical supply. Assessing the overall climate risk faced by this city would require to:

1. Determine the hazard expected impact on each of the six urban services identified. This can be achieved by iteratively applying Steps 2 and 3 to each service separately

Table 2
Resilience Indicators, by Dimension: Flexibility, Learning, and Governance

Resilience dimension	Resilience attributes	Justification	Examples of variables and indicators
Persistence/Flexibility	Ecosystem services and biodiversity	Conservation of ecosystems and biodiversity and the diversity of green/blue infrastructure offer more flexibility in the face of threats	Diversity and resilience of ecosystem services, and persistence of biodiversity (Lukasiewicz et al., 2016); green infrastructure (Carter et al., 2018; Derkzen et al., 2017); blue infrastructure (Pettinotti et al., 2018)
	Infrastructural diversity and redundancy	Adequate diversity, flexibility, and redundancy in infrastructure open up additional pathways when the main ones fail	Diversity and distribution in critical infrastructure, e.g., energy, transport, emergency, and social infrastructures (Carter et al., 2015; Forzieri et al., 2018)
	Livelihoods and financial resources	Access, distribution, and control of financial resources are essential to improve decision-making capability, mitigate damages, and facilitate response. Diversity, flexibility, and redundancy in livelihoods deliver more options in the face of threats	Financial capital and resources (Chirambo, 2017; Tinch et al., 2015); insurance access (Stechemesser et al., 2015); income levels and distribution (Carter et al., 2015); access to credit (Assan et al., 2018); economic development/stability (Matarrita-Cascante et al., 2017)
	Connectivity	Connectivity (mobility capacity and social networks) and communication networks allow greater collaboration, interchange of information, resources, and support in case of distress	Access to public transport (Carter et al., 2015); population mobility (capacity to travel) (Freitas et al., 2019); socio-ecological adaptation networks (Barnes et al., 2017; Woodruff, 2018); ITC's use (Bojovic et al., 2015)
Memory/learning	Available knowledge	The availability and integration of multiple types of knowledge (formal, experiential, and ancestral ones) promote an enhanced preparation in the face of present and future threats	Information and knowledge sharing instances (Karki et al., 2011); integration of traditional and scientific knowledge (Haque et al., 2014; Leon et al., 2015); education approaches (Cost, 2015)
	Risk planning and information management	Recording, assessment, and knowledge of past risks, as well as planning of future ones, allows for quicker and more effective responses and adaptations	Spatial planning regulations (Carter et al., 2015; Romero-Lankao et al., 2014); disaster preparedness plans (Smit & Wandel, 2006); evidence-based projections/scenarios (Cáceres-Arteaga et al., 2018); early alert/response systems (Cartwright et al., 2013)
	Reflexive mindset	Socio-cultural values, perceptions, and attitudes facing climate change-related risks mediate between the availability of coping/adaptation options and their effective deployment	Risk perception (Fuchs et al., 2017; Liu et al., 2013); awareness of climate change and its causes (Akhtar et al., 2019); acceptance and willingness to change; belief systems, worldviews, and cultural values (Jolliet et al., 2018; Parsons et al., 2018)
	Technology and innovation systems	Technological investments, as well as research and innovation systems, open new pathways of response or adaptation	Research (Brown et al., 2016; Espada et al., 2017); access and availability of technological adaptations (Moser et al., 2008; Pandey et al., 2016); % GDP in R&D (Juhola & Kruse, 2015)

Table 2
Continued

Resilience dimension	Resilience attributes	Justification	Examples of variables and indicators
Self-transformation/governance	Envisioning	The ability to anticipate future scenarios and build collective goals and targets directing action on the system's components and structure	Scenarios, participatory backcasting and forecasting exercises, policy and white papers, long-term strategies; visions and pathways (Avelino & Grin, 2017; Berkes et al., 2002; Folke et al., 2005; Loorbach, 2010; Voβ et al., 2009)
	Collective action and self-organization	Institutional self-organization capacity, collective decision-making, and diverse and effective stakeholder participation are fundamental for reflexive and polycentric governance of the system and its adaptations	Self-organization and community participation in decision-making (Bott & Braun, 2019; Szlafsztein, 2014); participatory vulnerability assessments (Smit & Wandel, 2006); possession of property rights over the resources (Ostrom et al., 2002; Poteete et al., 2010)
	Horizontal coordination	Social networks; trust and solidarity; mutuality; inclusivity and equality; shared norms, values, and goals, etc.) allow equitable collaboration between different stakeholders and incumbents, promoting the coherence in initiatives taken in different domains/sectors	Social capital (access to social networks, neighborhood safety, and information about hazards) (Romero-Lankao et al., 2014); presence of a strong kinship network (Smit & Wandel, 2006); firms (in)actions (Neise et al., 2018); gender equality (Assan et al., 2018; Hossain & Zaman, 2018); decision support framework (Palutikof et al., 2019; Thorne et al., 2015)
	Vertical coordination	Number, scope, quality, and connectivity in the relationships with regional, national, and supranational authorities, businesses, scientific actors, and the likes. Interscale mechanisms for shared learning and collaboration; common agendas and indicators	Cross-sectoral and scalar disaster management and adaptation responses (Carter et al., 2015; Cartwright et al., 2013); multilevel governance frameworks (Bauer & Steurer, 2014); top-down and bottom-up scenario building instances (Nilsson et al., 2017)

2. Determine additional sources of cross-disturbance between the services provided by each constitutive system and between systems by taking into account their interdependencies. In our example, disturbances affecting the ecosystem would cascade on the electrical supply (and possibly, on the well-being of the industrial market); simultaneously, a trade-off may exist between harnessing the ecosystem for hydroelectricity and have it available as a source of potable water
3. Determine the overall resilience of the System-of-Systems depending on the overarching governance structures of the city to balance the autonomy of the constitutive systems with coherence at the level of the System-of-Systems, e.g., by effectively employing integrate, multiscalar and polycentric approaches to governance, or by setting up intersectorial and interministerial coordination arrangements

The next step in our case study will involve participatory modeling techniques, and most particularly *fuzzy cognitive mapping* (Gray et al., 2015), which will be fed with the impact chains and interdependency maps cocreated with the local stakeholders to assess the possible impact of given threats, as well as of adaptation measures, on several components and services of the SoS. This approach provides a complete understanding of the relationships crossing through the city and affecting its resilience and vulnerability and generate a relevant and sound source of information for evidence-based decision-making in urban planning and adaptation.

5. Final Remarks

As the concept of urban resilience draws increasing attention as a way to support city planning, governance, and adaptation in the face of climate and environmental crises, there is a need for integrated frameworks spanning and articulating multiple usages and disciplinary perspectives on the notion. On this background, the present paper does not just aim to offer yet another set of indicators of urban resilience. It rather attempts to summarize and systematize different resilience interpretations often found in the literature and provide an integrated framework and methodological pipeline to streamline urban resilience in the context of climate risk assessment at a city level. As anticipated in Table 1, this approach explicitly struggles to embrace the diversity of services, threats, timeframes, processes, perspectives, and scales involved in urban risk and resilience.

The six analytical distinctions illustrated in Section 3 contribute to the literature by clarifying and doing justice to the different interpretations revolving across multiple disciplines and approaches concerning resilience. In particular, the specific reflection provided in Sections 3.4 and 3.5 about the "intentional" and "normative" dimensions of resilience is a significant contribution that, in our perspective, had been previously diagnosed but not significantly clarified in the existing literature. In any case, our proposed contribution is not simply to point the need to take into account the intentionality and normativity of resilience, but also to include these aspects into a broader analytical framework, which may account in an integrated way for different aspects and dimensions of resilience. Moreover, we also believe we are contributing to the body of knowledge by, first, explicitly linking up our proposal (and thus, standing advancements in risk and resilience assessments) with the conceptualization provided by IPCC, as well as disaster and risk management approaches. Second, connecting with the emerging literature on urban resilience and clarifying how a systemic and sociologically informed approach to risk and resilience assessment may be applied within urban planning in particular. Third, providing an explicit methodological protocol to streamline this kind of analysis within climate-related urban risk and resilience assessments, illustrated through specific examples from the Chilean case.

Thanks to these innovations, we mean our proposal to offer at once: (a) an integrated platform to support and articulate an interdisciplinary assessment of urban resilience and risk; (b) a coherent vantage point from which to observe the existing literature and "translating" results between disciplines and theoretical approaches; and (c) a reflexive perspective from which to guide and assess existing or proposed policies for urban governance. These insights were confirmed by our experience in the Chilean Climate Risk Atlas, briefly illustrated in the paper.

Noticeably, while our framework and methodological pipeline were specifically designed and tested in urban contexts and in the face of climate change-related threats, they could be generalized, with suitable adaptation, to all kinds of human settlements (urban and rural). Likewise, they could be extended to other kinds of nonclimate-related threats (e.g., earthquakes and other geological phenomena, or the impact of epidemics such as the Sars-CoV-2 we are currently experiencing). In the future, we hope that this framework may help inform evidence-based governance at multiple scales and in different contexts.

A corollary of our study refers to the challenges involved in the governance of resilient cities: in light of the interscale interdependencies and normative trade-offs linking up the resilience of a city's constitutive systems at the level of the System-of-Systems. We particularly stress the need for such governance to adopt distributed, participatory, and polycentric approaches able to balance the autonomy and coherence to ensure cities' overall resilience in the face of climate-related threats and hazards.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Bibliometric data used to construct the topic model referred to in Section 2 are available at: Billi, Marco, 2020, "Replication Data for: An Integrated Framework to Streamline Urban Resilience in the Context of Climate Risk Assessment," https://doi.org/10.7910/DVN/FRQ5ZC, Harvard Dataverse.

Acknowledgments
This work was supported by the Center for Climate and Resilience Research, FONDAP nº 15110009.

References

Abram, N., Gattuso, J.-P., Prakash, A., Cheng, L., Chidichimo, M. P., Crate, S., et al. (2019). Chapter I: Framing and context of the report. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, et al. (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate*. IPCC.

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, *100*(4), 341–343. https://doi.org/10.1016/j.landurbplan.2011.02.021

Ainuddin, S., & Routray, J. K. (2012). Community resilience framework for an earthquake prone area in Baluchistan. *International Journal of Disaster Risk Reduction*, *2*, 25–36. https://doi.org/10.1016/j.ijdrr.2012.07.003

Akhtar, R., Masud, M. M., & Afroz, R. (2019). Perception of climate change and the adaptation strategies and capacities of the rice farmers in Kedah, Malaysia. *Environment and Urbanization ASIA*, *10*(1), 99–115. https://doi.org/10.1177/0975425318822338

Alexander, D. E. (2013). Resilience and disaster risk reduction: An etymological journey. *Natural Hazards and Earth System Sciences*, *13*(11), 2707–2716. https://doi.org/10.5194/nhess-13-2707-2013

Allen, C. R., Angeler, D. G., Garmestani, A. S., Gunderson, L. H., & Holling, C. S. (2014). Panarchy: Theory and application. *Ecosystems*, *17*(4), 578–589. https://doi.org/10.1007/s10021-013-9744-2

Assan, E., Suvedi, M., Schmitt Olabisi, L., & Allen, A. (2018). Coping with and adapting to climate change: A gender perspective from smallholder farming in Ghana. *Environments*, *5*(8), 86. https://doi.org/10.3390/environments5080086

Astaraie-Imani, M., Kapelan, Z., Fu, G. T., & Butler, D. (2012). Assessing the combined effects of urbanisation and climate change on the river water quality in an integrated urban wastewater system in the UK. *Journal of Environmental Management*, *112*, 1–9. https://doi.org/10.1016/j.jenvman.2012.06.039

Avelino, F., & Grin, J. (2017). Environmental innovation and societal transitions beyond deconstruction: A reconstructive perspective on sustainability transition governance. *Environmental Innovation and Societal Transitions*, *22*, 15–25. https://doi.org/10.1016/j.eist.2016.07.003

Baggio, J. A., Brown, K., & Hellebrandt, D. (2015). Boundary object or bridging concept? A citation network analysis of resilience. *Ecology and Society*, *20*(2), 2. https://doi.org/10.5751/ES-07484-200202

Bai, X. (2018). Six research priorities for cities and climate change. *Nature Climate Change*, *555*, 23–25. https://doi.org/10.1038/d41586-018-02409-z

Balica, S. F., Wright, N. G., & van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural Hazards*, *64*(1), 73–105. https://doi.org/10.1007/s11069-012-0234-1

Barnes, M. L., Guerrero, A. M., Mcallister, R. R. J., Alexander, S. M., & Robins, G. (2017). The social structural foundations of adaptation and transformation in social—Ecological systems. *Ecology and Society*, *22*(4), 16. https://doi.org/10.5751/ES-09769-220416

Barthel, S., Parker, J., & Ernstson, H. (2015). Food and green space in cities: A resilience lens on gardens and urban environmental movements. *Urban Studies*, *52*(7), 1321–1338. https://doi.org/10.1177/0042098012472744

Bauer, A., & Steurer, R. (2014). Multi-level governance of climate change adaptation through regional partnerships in Canada and England. *Geoforum*, *51*, 121–129. https://doi.org/10.3934/environsci.2017.6.730

Beck, U. (2006). Reflexive governance: Politics in the global risk society. In J.-P. Voss, D. Bauknecht, & R. Kemp (Eds.), *Reflexive governance for sustainable development*. Edward Elgar Publishing.

Bennett, E. M., & Garry, D. (2009). Understanding relationships among multiple ecosystem services. *Ecology Letters*, *12*, 1394–1404. https://doi.org/10.1111/j.1461-0248.2009.01387.x

Berke, P. R., & Campanella, T. J. (2006). Planning for postdisaster resiliency. *The Annals of the American Academy of Political and Social Science*, *604*, 192–207. https://doi.org/10.1177/0002716205285533

Berkes, F., Colding, J., & Folke, C. (Eds.), (2002). social-ecological systems. *Building resilience for complexity and change*. Cambridge, UK: Cambridge University Press.

Biggs, R., Schlüter, M., & Schoon, M. L. (Eds.), (2015). *Principles for building resilience*. Sustaining ecosystem services in social-ecological systems. Cambridge, UK: Cambridge University Press.

Billi, M., Blanco, G., & Urquiza, A. (2019). What is the 'Social' in climate change research? A case study on scientific representations from Chile. *Minerva*, *57*(3), 293–315. https://doi.org/10.1007/s11024-019-09369-2

Billi, M., Mascareño, A., & Edwards, J. (2021). Governing sustainability or sustainable governance? Semantic constellations on the sustainability-governance intersection in academic literature. *Journal of Cleaner Production*, *279*, 123523. https://doi.org/10.1016/j.jclepro.2020.123523

Blei, D. M. (2012). Probabilistic topic models. *Communications of the ACM*, *55*(4), 77–84. https://doi.org/10.1145/2133806.2133826

Bobb, J. F., Peng, R. D., Bell, M. L., & Dominici, F. (2014). Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives*, *122*(8), 811–816. https://doi.org/10.1289/ehp.1307392

Bojovic, D., Bonzanigo, L., Giupponi, C., & Maziotis, A. (2015). Online participation in climate change adaptation: A case study of agricultural adaptation measures in Northern Italy. *Journal of Environmental Management*, *157*, 8–19. https://doi.org/10.1016/j.jenvman.2015.04.001

Bott, L. M., & Braun, B. (2019). How do households respond to coastal hazards? A framework for accommodating strategies using the example of Semarang Bay, Indonesia. *International Journal of Disaster Risk Reduction*, *37*, 101177. https://doi.org/10.1016/j.ijdrr.2019.101177

Brand, F. S., & Jax, K. (2007). Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecology and Society*, *12*(1), 23. https://doi.org/10.5751/es-02029-120123

Brondizio, E. S., O'brien, K., Bai, X., Biermann, F., Steffen, W., Berkhout, F., et al. (2016). Re-conceptualizing the Anthropocene: A call for collaboration. *Global Environmental Change*, *39*, 318–327. https://doi.org/10.1016/j.gloenvcha.2016.02.006

Brown, P. R., Bridle, K. L., & Crimp, S. J. (2016). Assessing the capacity of Australian broadacre mixed farmers to adapt to climate change: Identifying constraints and opportunities. *Agricultural Systems*, *146*, 129–141. https://doi.org/10.1016/j.agsy.2016.05.002

Cabieses, B., Cookson, R., Espinoza, M., Santorelli, G., & Delgado, I. (2015). Did socioeconomic inequality in self-reported health in chile fall after the equity-based healthcare reform of 2005? A concentration index decomposition analysis. *PLoS One*, *10*(9), e0138227. https://doi.org/10.1371/journal.pone.0138227

Cáceres-Arteaga, N., Ayala-Campaña, O., Rosero-Vaca, D., & Lane, D. K. M. (2018). Que nos depara el futuro? Análisis climático histórico y proyección de escenarios climáticos futuros para el cantón andino de Pedro Moncayo, Ecuador. *Revista Geográfica de América Central*, *3*(61E), 297–318. https://doi.org/10.15359/rgac.61-3.15

Carpenter, S. R., & Brock, W. A. (2008). Adaptive capacity and traps. *Ecology and Society*, *13*(2), 40. https://doi.org/10.5751/es-02716-130240[online]

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, *95*, 1–66. https://doi.org/10.1016/j.progress.2013.08.001

Carter, J. G., Handley, J., Butlin, T., & Gill, S. (2018). Adapting cities to climate change-exploring the flood risk management role of green infrastructure landscapes. *Journal of Environmental Planning and Management*, *61*(9), 1535–1552. https://doi.org/10.1080/09640568.2017.1355777

Cartwright, A., Blignaut, J., De Wit, M., Goldberg, K., Mander, M., O'Donoghue, S., & Roberts, D. (2013). Economics of climate change adaptation at the local scale under conditions of uncertainty and resource constraints: The case of Durban, South Africa. *Environment and Urbanization*, *25*(1), 139–156. https://doi.org/10.1177/0956247813477814

Cavalcante, E., Cacho, N., Lopes, F., Batista, T., & Oquendo, F. (2016). Thinking smart cities as systems-of-systems: A perspective study. In *Proceedings of the 2nd International Workshop on Smart Cities (SmartCities 2016) at ACM/IFIP USENIX Middleware* (Vol. 9, pp. 1–4). ACM.

Chaffin, B. C., Garmestani, A. S., Gunderson, L. H., Benson, M. H., Angeler, D. G., Anthony, C., et al. (2016). Transformative environmental governance. *Annual Review of Environment and Resources*, *41*(12), 399–423. https://doi.org/10.1146/annurev-environ-110615-085817

Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, *19*(3), 56. https://doi.org/10.5751/ES-06824-190356

Chaffin, B. C., & Gunderson, L. H. (2016). Emergence, institutionalization and renewal: Rhythms of adaptive governance in complex social-ecological systems. *Journal of Environmental Management*, *165*, 81–87. https://doi.org/10.1016/j.jenvman.2015.09.003

Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., et al. (2010). Ecosystem stewardship: Sustainability strategies for a rapidly changing planet. *Trends in Ecology and Evolution*, *25*(4), 241–249. https://doi.org/10.1016/j.tree.2009.10.008

Chapin, F. S., Folke, C., & Kofinas, G. P. (2009). A framework for understanding change. In F. S. Chapin, G. P. Kofinas, & C. Folke (Eds.), *Principles of ecosystem Stewardship resilience-based natural resource management in a changing world* (pp. 3–28). New York, NY: Springer. https://doi.org/10.1007/978-0-387-73033-2_1

Chirambo, D. (2017). Increasing the value of climate finance in an uncertain environment: Diaspora financial resources as a source of climate finance for Sub-Saharan Africa. *AIMS Environmental Science*, *4*(6), 730–742. https://doi.org/10.3934/environsci.2017.6.730

Cook-Patton, S. C., & Bauerle, T. L. (2012). Potential benefits of plant diversity on vegetated roofs: A literature review. *Journal of Environmental Management*, *106*, 85–92. https://doi.org/10.1016/j.jenvman.2012.04.003

Cosens, B. A., Gunderson, L., & Chaffin, B. C. (2018). Introduction to the special feature practicing panarchy: Assessing legal flexibility, ecological resilience, and adaptive governance in regional water systems experiencing rapid environmental change. *Ecology and Society*, *23*(1), 4. https://doi.org/10.5751/ES-09524-230104

Cost, D. S. (2015). The role of public education in governance for resilience in a rapidly changing arctic. *Ecology and Society*, *20*(3), 1–11. https://doi.org/10.5751/ES-07757-200329

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Web, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster resilience indicators for benchmarking baseline conditions. *Journal of Homeland Security and Emergency Management*, *7*(1), 51. https://doi.org/10.2202/1547-7355.1732

D'Amato, D., Droste, N., Allen, B., & Toppinen, A. (2017). Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production*, *168*, 716–734. https://doi.org/10.1016/j.jclepro.2017.09.053

Dankel, D. J., Vaage, N. S., & van der Sluijs, J. P. (2017). Post-normal science in practice. *Futures*, *91*, 1–4. https://doi.org/10.1016/j.futures.2017.05.009

DeCaro, D. A., Chaffin, B. C., Schlager, E., Garmestani, A. S., & Ruhl, J. B. (2017). Legal and institutional foundations of adaptive environmental governance. *Ecology and Society*, *22*(1), 32. https://doi.org/10.5751/ES-09036-220132

Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning*, *157*, 106–130. https://doi.org/10.1016/j.landurbplan.2016.05.027

Desouza, K. C., & Flanery, T. H. (2013). Designing, planning, and managing resilient cities: A conceptual framework. *Cities*, *35*, 89–99. https://doi.org/10.1016/j.cities.2013.06.003

Djordjevic, S., Butler, D., Gourbesville, P., Mark, O., & Pasche, E. (2011). New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: The CORFU approach. *Environmental Science and Policy*, *14*(7), 864–873. https://doi.org/10.1016/j.envsci.2011.05.008

Duit, A., & Galaz, V. (2008). Governance and complexity—emerging issues for governance theory. *Governance*, *21*(3), 311–335. https://doi.org/10.1111/j.1468-0491.2008.00402.x

Eakin, H., Lerner, A. M., & Murtinho, F. (2010). Adaptive capacity in evolving peri-urban spaces: Responses to flood risk in the upper lerma river valley, Mexico. *Global Environmental Change-Human Policy Dimens*, *20*(1), 14–22. https://doi.org/10.1016/j.gloenvcha.2009.08.005

Eraydin, A., & Tasan-Kok, T. (Eds.), (2013). *Resilience thinking in urban planning*. Dordrecht, Heidelberg, New York & London: Springer.

Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Olsson, P., Gaffney, O., et al. (2019). Sustainability and resilience for transformation in the urban century. *Nature Sustainability*, *2*(4), 267–273. https://doi.org/10.1038/s41893-019-0250-1

Ernstson, H., Leeuw, S. E. V. D., Redman, C. L., Meffert, D. J., Davis, G., Alfsen, C., et al. (2010). Urban transitions: On urban resilience and human-dominated ecosystems. *Ambio*, *39*, 531–545. https://doi.org/10.1007/s13280-010-0081-9

Espada, R., Apan, A., & McDougall, K. (2017). Vulnerability assessment of urban community and critical infrastructures for integrated flood risk management and climate adaptation strategies. *International Journal of Disaster Resilience in the Built Environment*, *8*(4), 375–411. https://doi.org/10.1108/IJDRBE-03-2015-0010

Feola, G. (2015). Societal transformation in response to global environmental change: A review of emerging concepts. *Ambio*, *44*, 376–390. https://doi.org/10.1007/s13280-014-0582-z

Ferguson, B. C., Brown, R. R., Frantzeskaki, N., de Haan, F. J., & Deletic, A. (2013). The enabling institutional context for integrated water management: Lessons from Melbourne. *Water Research*, *47*(20), 7300–7314. https://doi.org/10.1016/j.watres.2013.09.045

Fernandes, P. M. (2013). Fire-smart management of forest landscapes in the Mediterranean basin under global change. *Landscape and Urban Planning*, *110*, 175–182. https://doi.org/10.1016/j.landurbplan.2012.10.014

Fernández, I. C., & Wu, J. (2016). Assessing environmental inequalities in the city of Santiago (Chile) with a hierarchical multiscale approach. *Applied Geography*, *74*, 160–169. https://doi.org/10.1016/j.apgeog.2016.07.012

Folke, C. (2016). Resilience. In *Oxford Research Encyclopedia of Environmental Science*. Oxford University Press. https://doi.org/10.1093/acrefore/9780199389414.013.8

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, *30*, 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Forzieri, G., Bianchi, A., Silva, F. B., Marin Herrera, M. A., Leblois, A., Lavalle, C., et al. (2018). Escalating impacts of climate extremes on critical infrastructures in Europe. *Global Environmental Change*, *48*, 97–107. https://doi.org/10.1016/j.gloenvcha.2017.11.007

Freitas, C. R., D'Avignon, A. L. de A., & Castro, A. C. (2019). Urban social vulnerability and climate change in Rio de Janeiro city associated with population mobility. *Journal of Environmental Policy and Planning*, *21*(6), 797–810. https://doi.org/10.1080/1523908X.2019.1674135

Fu, Y., & Zhang, X. (2017). Trajectory of urban sustainability concepts: A 35-year bibliometric analysis. *Cities*, *60*, 113–123. https://doi.org/10.1016/j.cities.2016.08.003

Fuchs, S., Karagiorgos, K., Kitikidou, K., Maris, F., Paparrizos, S., & Thaler, T. (2017). Flood risk perception and adaptation capacity: A contribution to the socio-hydrology debate. *Hydrology and Earth System Sciences*, *21*(6), 3183–3198. https://doi.org/10.5194/hess-21-3183-2017

Funtowicz, S., & Ravetz, J. (2003). Post-normal science. *Ecological Economics*, (Feb), 1–10. https://doi.org/10.1007/978-3-8350-9053-8_13

Galaitsi, S. E., Keisler, J. M., Trump, B. D., & Linkov, I. (2020). The need to reconcile concepts that characterize systems facing threats. *Risk Analysis*, *41*, 3–21. https://doi.org/10.1111/risa.13577

Ganin, A. A., Kitsak, M., Marchese, D., Keisler, J. M., Seager, T., & Linkov, I. (2017). Resilience and efficiency in transportation networks. *Science Advances*, *3*(12), e1701079. https://doi.org/10.1126/sciadv.1701079

Garmestani, A. S., Allen, C. R., & Gunderson, L. (2009). Panarchy: Discontinuities reveal similarities in the dynamic system. *Ecology and Society*, *14*(1), 15. https://doi.org/10.5751/es-02744-140115

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: Introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, *24*, 471–482. https://doi.org/10.1016/j.jtrangeo.2012.01.021

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society*, *29*(4), 441–455. https://doi.org/10.1016/j.techsoc.2007.08.009

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

GIZ. (2016). *The vulnerability sourcebook. Adephi y EURAC*. Retrieved from https://www.adelphi.de/en/publication/vulnerability-sourcebook-concept-and-guidelines-standardised-vulnerability-assessments

GIZ. (2017). *Risk supplement to the vulnerability sourcebook, GIZ (Ministerio Federal de Cooperación Económica y Desarrollo), Adephi y EURAC*. Retrieved from http://www.adaptationcommunity.net/wp-content/uploads/2017/10/GIZ-2017_Risk-Supplement-to-the-Vulnerability-Sourcebook.pdf

GIZ. (2018). *Introduction to the Water-Energy-Food Security (WEF) NEXUS*. GM: Nexus Regional Dialogue Programme (NRD).

Gomez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Gotts, N. (2007). Resilience, panarchy, and world-systems analysis. *Ecology and Society*, *12*(1), 24–37. https://doi.org/10.5751/es-02017-120124

Gray, S. A., Gray, S., de Kok, J. L., Helfgott, A. E. R., O'Dwyer, B., Jordan, R., & Nyaki, A. (2015). Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. *Ecology and Society*, *20*(2), 11. https://doi.org/10.5751/ES-07396-200211

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Gunderson, L., Cosens, B. A., Chaffin, B. C., Arnold, C. A. T., Fremier, A. K., Ahjond, S., et al. (2017). Regime shifts and panarchies in regional scale social-ecological water systems. *Ecology and Society*, *22*(1), 31. https://doi.org/10.5751/ES-08879-220131

Gunderson, L., & Holling, C. (2002). *Panarchy: Understanding transformations in human and natural systems*. Island Press.

Hahn, T., & Nykvist, B. (2017). Are adaptations self-organized, autonomous, and harmonious? Assessing the social-ecological resilience literature. *Ecology and Society*, *22*(1), 12. https://doi.org/10.5751/ES-09026-220112

Haque, M. A., Louis, V. R., Phalkey, R., & Sauerborn, R. (2014). Use of traditional medicines to cope with climate-sensitive diseases in a resource poor setting in Bangladesh. *BMC Public Health*, *14*(1), 202. https://doi.org/10.1186/1471-2458-14-202

Hodbod, J., & Adger, W. N. (2014). Integrating social-ecological dynamics and resilience into energy systems research. *Energy Research and Social Science*, *1*, 226–231. https://doi.org/10.1016/j.erss.2014.03.001

Hodge, B. (2013). The hydra paradox: Global disaster management in a world of crises. *Globalizations*, *10*(3), 355–366. https://doi.org/10.1080/14747731.2013.787781

Holling, C. S. (1996). Engineering resilience versus ecological resilience. In P. Schulze (Ed.), *Engineering within ecological constraints* (pp. 31–43). National Academies Press. Retrieved from http://www.nap.edu/openbookI0309051983/htmI/31.html

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-001-0101-5

Hollling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*, 1–23. https://doi.org/10.1146/annurev.es.4.082406.100001

Horowitz, L. S. (2013). Toward empathic agonism: Conflicting vulnerabilities in urban wetland governance. *Environment and Planning A*, *45*(10), 2344–2361. https://doi.org/10.1068/a45591

Hossain, K. M., & Zaman, F. (2018). Unravelling coastal people's adaptation to salinity: Evidence from Bangladesh. *International Journal of Environment and Sustainable Development*, *17*(1), 70–92. https://doi.org/10.1504/IJESD.2018.089278

Hosseini, S., Barker, K., & Ramirez-Marquez, J. E. (2016). A review of definitions and measures of system resilience. *Reliability Engineering and System Safety*, *145*, 47–61. https://doi.org/10.1016/j.ress.2015.08.006

Huneeus, C., Avendaño, O., & Ahumada, P. (2018). *El sistema político de Chile*. LOM Ediciones.

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: A review of the literature. *Climate Change*, *104*(1), 13–49. https://doi.org/10.1007/s10584-010-9975-6

IPCC. (2014). *AR5 climate change 2014: Impacts, adaptation and vulnerability*. IPCC.

Jabeen, H., Johnson, C., & Allen, A. (2010). Built-in resilience: Learning from grassroots coping strategies for climate variability. *Environment and Urbanization*, *22*(2), 415–431. https://doi.org/10.1177/0956247810379937

Jakes, P. J., & Langer, E. R. (2012). The adaptive capacity of New Zealand communities to wildfire. *International Journal of Wildland Fire*, *21*(6), 764–772. https://doi.org/10.1071/WF11086

Jelodar, H., Wang, Y., Yuan, C., & Feng, X. (2017). *Latent Dirichlet Allocation (LDA) and topic modeling: Models, applications: A survey*. arXiv:1711.04305.

Jolliet, O., Antón, A., Boulay, A. M., Cherubini, F., Fantke, P., Levasseur, A., et al. (2018). Global guidance on environmental life cycle impact assessment indicators: Impacts of climate change, fine particulate matter formation, water consumption and land use. *International Journal of Life Cycle Assessment*, *23*(11), 2189–2207. https://doi.org/10.1007/s11367-018-1443-y

Juhola, S., & Kruse, S. (2015). A framework for analysing regional adaptive capacity assessments: Challenges for methodology and policy making. *Mitigation and Adaptation Strategies for Global Change*, *20*(1), 99–120. https://doi.org/10.1007/s11027-013-9481-z

Kammen, D. M., & Sunter, D. A. (2016). City-integrated renewable energy for urban sustainability. *Science*, *352*(6288), 922–928. https://doi.org/10.1126/science.aad9302

Karki, M. B., Shrestha, A. B., & Winiger, M. (2011). Enhancing knowledge management and adaptation capacity for integrated management of water resources in the indus river basin. *Mountain Research and Development*, *31*(3), 242–251. https://doi.org/10.1659/mrd-journal-d-11-00017.1

Karrholm, M., Nylund, K., & de la Fuente, P. P. (2014). Spatial resilience and urban planning: Addressing the interdependence of urban retail areas. *Cities*, *36*, 121–130. https://doi.org/10.1016/j.cities.2012.10.012

Konrad, K. (2010). Governance of and by Expectations. In A. Bonaccorsi, S. Borras, S. Cozzens, B. R. Dorbeck-Jung, C. Edquist, J. Enders, et al. (Eds.), *Tentative Governance in Emerging Science and Technology: Actor Constellations, Institutional Arrangements and Strategies* (p. 67). Institute of Innovation and Governance Studies-University of Twente.

Kouroussis, G., Pauwels, N., Brux, P., Conti, C., & Verlinden, O. (2014). A numerical analysis of the influence of tram characteristics and rail profile on railway traffic ground-borne noise and vibration in the Brussels Region. *The Science of the Total Environment*, *482*, 452–460. https://doi.org/10.1016/j.scitotenv.2013.05.083

Lawhon, M., & Murphy, J. T. (2012). Socio-technical regimes and sustainability transitions: Insights from political ecology. *Progress in Human Geography*, *36*(3), 354–378. https://doi.org/10.1177/0309132511427960

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, *3*(3), 164–168. https://doi.org/10.1016/j.cosust.2010.12.014

Leon, J. X., Hardcastle, J., James, R., Albert, S., Kereseka, J., & Woodroffe, C. D. (2015). Supporting local and traditional knowledge with science for adaptation to climate change: Lessons learned from participatory three-dimensional modeling in BoeBoe, Solomon Islands. *Coastal Management*, *43*(4), 424–438. https://doi.org/10.1080/08920753.2015.1046808

Linkov, I., Fox-Lent, C., Read, L., Allen, C. R., Arnott, J. C., Bellini, E., et al. (2018). Tiered approach to resilience assessment. *Risk Analysis*, *38*(9), 1772–1780. https://doi.org/10.1111/risa.12991

Linkov, I., & Trump, B. D. (2019). *The science and practice of resilience*. Springer International Publishing.

Liu, J. (2017). Integration across a metacoupled world. *Ecology and Society*, *22*(4), 29. https://doi.org/10.5751/ES-09830-220429

Liu, T., Xu, Y. J., Zhang, Y. H., Yan, Q. H., Song, X. L., Xie, H. Y., et al. (2013). Associations between risk perception, spontaneous adaptation behavior to heat waves and heatstroke in Guangdong province, China. *BMC Public Health*, *13*, 913. https://doi.org/10.1186/1471-2458-13-913

Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance: An International Journal of Policy, Administration, and Institutions*, *23*(1), 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

Luhmann, N. (1984). The self-description of society: Crisis fashion and sociological theory. *International Journal of Comparative Sociology*, *25*, 59–72. https://doi.org/10.1163/156854284x00052

Luhmann, N. (1995). *Social systems*. Stanford University Press.

Luhmann, N. (1997a). The control of intransparency. *Systems Research and Behavioral Science*, *14*(6), 359–371. https://doi.org/10.1002/(SICI)1099-1743(199711/12)14:6<359::AID-SRES160>3.0.CO;2-R

Luhmann, N. (1997b). *Die Gesellschaft der Gesellschaft*. Frankfurt: Suhrkamp.

Luhmann, N. (2007). *La Sociedad de la Sociedad*. Mexico, DF: Herder & Universidad Iberoamericana. https://doi.org/10.1017/CBO9781107415324.004

Lukasiewicz, A., Pittock, J., & Finlayson, M. (2016). Institutional challenges of adopting ecosystem-based adaptation to climate change. *Regional Environmental Change*, *16*(2), 487–499. https://doi.org/10.1007/s10113-015-0765-6

Mahmood, M. I., Elagib, N. A., Horn, F., & Saad, S. A. (2017). Lessons learned from Khartoum flash flood impacts: An integrated assessment. *Science of the Total Environment*, *601*, 1031–1045. https://doi.org/10.1016/j.scitotenv.2017.05.260

Martin, R., & Sunley, P. (2015). On the notion of regional economic resilience: Conceptualization and explanation. *Journal of Economic Geography*, *15*(1), 1–42. https://doi.org/10.1093/jeg/lbu015

Martin-Breen, P., & Anderies, J. M. (2011). *Resilience: A literature review*. Retrieved from https://opendocs.ids.ac.uk/opendocs/handle/123456789/3692

Matarrita-Cascante, D., Trejos, B., Qin, H., Joo, D., & Debner, S. (2017). Conceptualizing community resilience: Revisiting conceptual distinctions. *Community Development*, *48*(1), 105–123. https://doi.org/10.1080/15575330.2016.1248458

Maturana, H. R., & Varela, F. J. (1987). *The tree of knowledge: The biological roots of human understanding*. New Science Library/Shambhala Publications.

McCarthy, M. P., Best, M. J., & Betts, R. A. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters*, *37*, L09705. https://doi.org/10.1029/2010GL042845

Meerow, S., & Newell, J. P. (2015). Resilience and complexity: A bibliometric review and prospects for industrial ecology. *Journal of Industrial Ecology*, *19*(2), 236–251. https://doi.org/10.1111/jiec.12252

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, *147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Meza, F., Vicuña, S., Gironás, J., Poblete, D., Suárez, F., & Oertel, M. (2015). Water-food-energy nexus in Chile: The challenges due to global change in different regional contexts. *Water International*, *40*(5–6), 839–855. https://doi.org/10.1080/02508060.2015.1087797

Midgley, G. (2003). *Systems thinking*. London: SAGE.

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., et al. (2010). Resilience and vulnerability: Complementary or conflicting concepts? *Ecology and Society*, *15*(3), 11. https://doi.org/10.5751/es-03378-150311
Moran, D., Kanemoto, K., Jiborn, M., Wood, R., Többen, J., & Seto, K. C. (2018). Carbon footprints of 13,000 cities. *Environmental Research Letters*, *13*(6), 064041. https://doi.org/10.1088/1748-9326/aac72a
Moser, S. C., Kasperson, R. E., Yohe, G., & Agyeman, J. (2008). Adaptation to climate change in the Northeast United States: Opportunities, processes, constraints. *Mitigation and Adaptation Strategies for Global Change*, *13*(5–6), 643–659. https://doi.org/10.1007/s11027-007-9132-3
Neise, T., Revilla Diez, J., & Garschagen, M. (2018). Firms as drivers of integrative adaptive regional development in the context of environmental hazards in developing countries and emerging economies—A conceptual framework. *Environment and Planning C: Politics and Space*, *36*(8), 1522–1541. https://doi.org/10.1177/2399654418771079
Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. *PLoS One*, *10*(3), e0118571. https://doi.org/10.1371/journal.pone.0118571
Nilsson, A. E., Bay-Larsen, I., Carlsen, H., van Oort, B., Bjørkan, M., Jylhä, K., et al. (2017). Towards extended shared socioeconomic pathways: A combined participatory bottom-up and top-down methodology with results from the Barents region. *Global Environmental Change*, *45*, 124–132. https://doi.org/10.1016/j.gloenvcha.2017.06.001
Norberg, J., & Cumming, G. S. (2008). *Complexity theory for a sustainable future*. New York, NY: Columbia University Press.
Novak, D. C., & Sullivan, J. L. (2014). A link-focused methodology for evaluating accessibility to emergency services. *Decision Support Systems*, *57*, 309–319. https://doi.org/10.1016/j.dss.2013.09.015
O'Brien, K. (2012). Global environmental change II: From adaptation to deliberate transformation. *Progress in Human Geography*, *36*, 667–676. https://doi.org/10.1177/0309132511425767
OECD. (2016). *Income inequality remains high in the face of weak recovery. Income Inequality Update*. Retrieved from http://oe.cd/idd
Olsson, L., Jerneck, A., Thoren, H., Persson, J., & O'Byrne, D. (2015). Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience. *Science Advances*, *1*(4), e1400217. https://doi.org/10.1126/sciadv.1400217
Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.
Ostrom, E. (2009). *A polycentric approach for coping with climate change*. Background Paper to the 2010 World Development Report (Policy Research Working Paper No. 5095).
Ostrom, E., Diets, T., Dolsak, N., Ster, P., Stonich, S., & Webwe, E. (Eds.), (2002). National Research Council, Comittee on De Human Dimensions of Global Chanche *The Drama of the Commons*. Washington, DC: National Academy Press. https://doi.org/10.17226/10287
Ouyang, M., Dueñas-Osorio, L., & Min, X. (2012). A three-stage resilience analysis framework for urban infrastructure systems. *Structural Safety*, *36–37*, 23–31. https://doi.org/10.1016/j.strusafe.2011.12.004
Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy*, *23*, 24–34. https://doi.org/10.1016/j.envsci.2012.07.014
Palutikof, J. P., Rissik, D., Webb, S., Tonmoy, F. N., Boulter, S. L., Leitch, A. M., et al. (2019). CoastAdapt: An adaptation decision support framework for Australia's coastal managers. *Climatic Change*, *153*(4), 491–507. https://doi.org/10.1007/s10584-018-2200-8
Pandey, R., Maithani, N., Aretano, R., Zurlini, G., Archie, K. M., Gupta, A. K., & Pandey, V. P. (2016). Empirical assessment of adaptation to climate change impacts of mountain households: Development and application of an adaptation capability index. *Journal of Mountain Science*, *13*(8), 1503–1514. https://doi.org/10.1007/s11629-015-3499-5
Parsons, M., Brown, C., Nalau, J., & Fisher, K. (2018). Assessing adaptive capacity and adaptation: Insights from Samoan tourism operators. *Climate and Development*, *10*(7), 644–663. https://doi.org/10.1080/17565529.2017.1410082
Perrow, C. (1984). *Normal accidents. Living with high-risk technologies*. BasicBooks.
Pettinotti, L., de Ayala, A., & Ojea, E. (2018). Benefits from water related ecosystem services in Africa and climate change. *Ecological Economics*, *149*, 294–305. https://doi.org/10.1016/j.ecolecon.2018.03.021
Pickett, S., Cadenasso, M., & Grove, J. (2004). Resilient cities: Meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning*, *69*(4), 369–384. https://doi.org/10.1016/j.landurbplan.2003.10.035
Pickett, S., Cadenasso, M. L., & McGrath, B. (Eds.), (2013). *Resilience in ecology and urban design: Linking theory and practice for sustainable cities*. Springer.
Pickett, S. T. A., Cadenasso, M. L., & Grove, J. M. (2004). Resilient cities: Meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning*, *69*(4), 369–384. https://doi.org/10.1016/j.landurpbplan.2003.10.035
Pizzo, B. (2015). Problematizing resilience: Implications for planning theory and practice. *Cities*, *43*, 133–140. https://doi.org/10.1016/j.cities.2014.11.015
Poteete, A., Janssen, M., & Ostrom, E. (2010). *Working together: Collective action, the commons, and multiple methods in practice*. Princeton University Press. https://doi.org/10.1093/ndt/gfh1007
Prieto Barboza, E. A. (2013). Resiliencia y panarquía: Claves para enfrentar la adversidad en sistemas sociales. *Multiciencias*, *13*(1), 23–29. Retrieved from http://www.redalyc.org/pdf/904/90428348007.pdf
RedPE. (2019). *Pobreza Energética: El Acceso Desigual a Energía de Calidad como Barrera para el Desarrollo en Chile*. Santiago, Universidad de Chile. http://redesvid.uchile.cl/pobreza-energetica/documentos-redpe/
Rip, A. (2012). The context of innovation journeys. *Creativity and Innovation Management*, *21*(2), 158–170. https://doi.org/10.1111/j.1467-8691.2012.00640.x
Ritchie, H., & Roser, M. (2018). *Urban population (%) long-run with 2050 projections (OWID)*. Retrieved from https://ourworldindata.org/urbanization#targetText=Since_the_crossing_point_in, and 3.4 billion in rural.
Romero-Lankao, P., Hughes, S., Qin, H., Hardoy, J., Rosas-Huerta, A., Borquez, R., & Lampis, A. (2014). Scale, urban risk and adaptation capacity in neighborhoods of Latin American cities. *Habitat International*, *42*, 224–235. https://doi.org/10.1016/j.habitatint.2013.12.008
Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., et al. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, *15*(1), 95–111. https://doi.org/10.1186/s12940-016-0103-6
Scheffer, M., Westley, F., Brock, W. A., & Holmgren, M. (2002). Dynamic interactions of societies and ecosystems. In L. H. Gunderson, & C. S. Hollling (Eds.), *Panarchy. Understanding transformations in human and natural systems* (pp. 195–239). Washington, Covelo, London: Island Press.
Schiappacasse, P., & Müller, B. (2018). One fits all? Resilience as a multipurpose concept in regional and environmental development. *Raumforschung und Raumordnung Spatial Research and Planning*, *76*(1), 51–64. https://doi.org/10.1007/s13147-018-0520-9
Schober, A., Simunovic, N., Darabant, A., & Stern, T. (2018). Identifying sustainable forest management research narratives: A text mining approach. *Journal of Sustainable Forestry*, *37*, 537–554. https://doi.org/10.1080/10549811.2018.1437451

Sietz, D., & Feola, G. (2016). Resilience in the rural Andes: Critical dynamics, constraints and emerging opportunities. *Regional Environmental Change*, *16*(8), 2163–2169. https://doi.org/10.1007/s10113-016-1053-9

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Smith, A., & Stirling, A. (2010). The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society*, *15*, 13. https://doi.org/10.5751/es-03218-150111

Stechemesser, K., Endrikat, J., Grasshoff, N., & Guenther, E. (2015). Insurance companies' responses to climate change: Adaptation, dynamic capabilities and competitive advantage. *The Geneva Papers on Risk and Insurance-Issues and Practice*, *40*(4), 557–584. https://doi.org/10.1057/gpp.2015.1

Steyvers, M., & Griffiths, T. (2007). Probabilistic topic models. In T. Landauer, D. McNamara, S. Dennis, & W. Kintsch (Eds.), *Latent semantic analysis: A road to meaning* (pp. 2–15). Laurence Erlbaum.

Szlafsztein, C. F. (2014). Development projects for small rural communities in the Brazilian Amazon region as potential strategies and practices of climate change adaptation. *Mitigation and Adaptation Strategies for Global Change*, *19*(2), 143–160. https://doi.org/10.1007/s11027-012-9431-1

Tejada, M. M. (2016). Lifetime inequality measures for an emerging economy: The case of Chile. *Labour Economics*, *42*, 1–15. https://doi.org/10.1016/j.labeco.2016.06.002

Thoren, H. (2014). Resilience as a unifying concept. *International Studies in the Philosophy of Science*, *28*(3), 303–324. https://doi.org/10.1080/02698595.2014.953343

Thorne, K. M., Mattsson, B. J., Takekawa, J., Cummings, J., Crouse, D., Block, G., et al. (2015). Collaborative decision-analytic framework to maximize resilience of tidal marshes to climate change. *Ecology and Society*, *20*(1). https://doi.org/10.5751/es-07018-200130

Tinch, R., Jäger, J., Omann, I., Harrison, P. A., Wesely, J., & Dunford, R. (2015). Applying a capitals framework to measuring coping and adaptive capacity in integrated assessment models. *Climatic Change*, *128*(3–4), 323–337. https://doi.org/10.1007/s10584-014-1299-5

UNDP. (2019). *Human development report 2019: Beyond income, beyond averages, beyond today*. United Nations Development Program.

UNESCO. (2019). *Transforming the future. Anticipation in the 21st century*. UNESCO Publishing & Routledge. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000264644

United Nations. (2019a). *The urban nexus: Integrating resources for sustainable Cities Economic and Social Commission for Asia and the Pacific (ESCAP)*.

United Nations. (2019b). *World Urbanization Prospects: The 2018 Revision*. https://doi.org/10.18356/b9e995fe-en

Urquiza, A., Amigo, C., Billi, M., Brandão, G., & Morales, B. (2018). Metálogo como herramienta de colaboración transdisciplinaria. *Cinta de Moebio*, *62*, 182–198. https://doi.org/10.4067/S0717-554X2018000200182

Urquiza, A., Amigo, C., Billi, M., Calvo, R., Labraña, J., Oyarzún, T., & Valencia, F. (2019a). Quality as a hidden dimension of energy poverty in middle-development countries. Literature review and case study from Chile. *Energy and Buildings*, *204*, 109463. https://doi.org/10.1016/j.enbuild.2019.109463

Urquiza, A., Amigo, C., Billi, M., Cortés, J., & Labraña, J. (2019b). Gobernanza policéntrica y problemas ambientales en el siglo XXI: Desafíos de coordinación social para la distribución de recursos hídricos en Chile. *Persona y Sociedad*, *XXXIII*(1), 133–160.

Urquiza, A., Amigo, C., Billi, M., & Espinosa, P. (2019c). Participatory energy transitions as boundary-object-making: Systems-theoretical approximation and exploratory study of Chile's Energía2050. *Frontiers in Energy Research*, *6*(134).

Urquiza, A., & Billi, M. (2018). *Water markets and social-ecological resilience to water stress in the context of climate change: An analysis of the Limarí basin, Chile [en prensa]*. Environment, Development and Sustainability.

Urquiza, A., & Cadenas, H. (2015). Sistemas socio-ecológicos: Elementos teóricos y conceptuales para la discusión en torno a vulnerabilidad hídrica. *L'Ordinaire Des Amériques*, *218*. https://doi.org/10.4000/orda.1774 Haut de page Auteurs.

Vaas, J., Driessen, P. P. J., Giezen, M., Laerhoven, F. V., & Wassen, M. J. (2017). Who's in charge here anyway? Polycentric governance configurations and the development of policy on invasive alien species in the semisovereign. *Ecology and Society*, *22*(4), 1. https://doi.org/10.5751/ES-09487-220401

Vale, L. J. (2014). The politics of resilient cities: Whose resilience and whose city? *Building Research and Information*, *42*(2), 191–201. https://doi.org/10.1080/09613218.2014.850602

Voß, J. P., Smith, A., & Grin, J. (2009). Designing long-term policy: Rethinking transition management. *Policy Sciences*, *42*(4), 275–302. https://doi.org/10.1007/sl10.1007/s11077-009-9103-5

von Foerster, H. (1981). *Observing systems*. Intersystems Publications.

Walker, B., Holling, C., Carpenter, S., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, *9*(2), 5. https://doi.org/10.5751/es-00650-090205

Walker, B. H., & Salt, D. A. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Washington, DC: Island Press.

Wardekker, J. A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change*, *77*(6), 987–998. https://doi.org/10.1016/j.techfore.2009.11.005

Weerheijm, J., Mediavilla, J., & van Doormaal, J. C. A. M. (2009). Explosive loading of multi storey RC buildings: Dynamic response and progressive collapse. *Structural Engineering and Mechanics*, *32*(2), 193–212. https://doi.org/10.12989/sem.2009.32.2.193

Westley, F., Carpenter, S. R., Brock, W. A., Hollling, C. S., & Gunderson, L. H. (2002). Why Systems of people and nature are not just social and ecological systems. In L. H. Gunderson, & C. S. Hollling (Eds.), *Panarchy. Understanding transformations in human and natural systems* (pp. 103–120). Island Press.

Wiedemann, G. (2013). Opening up to big data: Computer-assisted analysis of textual data in social sciences. *Forum for Qualitative Social Research*, *14*(2), 23.

Willke, H. (2006). *Global governance*. Transcript.

Willke, H. (2016). Formas de autoorientación de la sociedad. *Revista MAD*, *34*, 1–35.

Wolf, J., Adger, W. N., Lorenzoni, I., Abrahamson, V., & Raine, R. (2010). Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. *Global Environmental Change-Human Policy Dimens*, *20*(1), 44–52. https://doi.org/10.1016/j.gloenvcha.2009.09.004

Wolfram, M., Frantzeskaki, N., & Maschmeyer, S. (2017). Cities, systems and sustainability: Status and perspectives of research on urban transformations. *Current Opinion in Environmental Sustainability*, *22*, 18–25. https://doi.org/10.1016/j.cosust.2017.01.014

Wong, D. F. K., & Song, H. X. (2008). The resilience of migrant workers in Shanghai China: The roles of migration stress and meaning of migration. *International Journal of Social Psychiatry*, *54*(2), 131–143. https://doi.org/10.1177/0020764007083877

Woodruff, S. C. (2018). City membership in climate change adaptation networks. *Environmental Science and Policy*, *84*, 60–68. https://doi.org/10.1016/j.envsci.2018.03.002

Xue, X., Wang, L., & Yang, R. J. (2018). Exploring the science of resilience: Critical review and bibliometric analysis. *Natural Hazards*, *90*(1), 477–510. https://doi.org/10.1007/s11069-017-3040-y

Zölch, T., Maderspacher, J., Wamsler, C., & Pauleit, S. (2016). Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale. *Urban Forestry and Urban Greening*, *20*, 305–316. https://doi.org/10.1016/j.ufug.2016.09.011

Reference From the Supporting Information

Westgate, M. J., Barton, P. S., Pierson, J. C., & Lindenmayer, D. B. (2015). Text analysis tools for identification of emerging topics and research gaps in conservation science. *Conservation Biology*, *29*(6), 1606–1614. https://doi.org/10.1111/cobi.12605