Climate Change resilience: indicators

ClimEmpower Work Package 2, D2.2, v1

Project ClimEmpower: User Driven Climate Applications Empowering Regional Resilience

Work package 2, Deliverable D2.2

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Legal Disclaimer

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List of Acronyms

AIT	Austrian Institute of Technology GmbH
ANDALUS	Consejería de Sostenibilidad, Medio ambiente y Economía Azul
CC	Climate Change
CDS	Climate Data Store
CIC	Climate interaction context
CLMS	Copernicus Land Monitoring Service
CoP	Community of Practice
CRA	Climate Resilient Agriculture
EFFIS	European Forest Fire Information System
EUROSTAT	European Statistical Office
FAO	Food and Agricultural Organization of the United Nations
FRC	Frederick Research Center
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre of the European Commission
KPI	Key Performance Indicator
OSM	OpenStreetMap
PAAC	Andalusian Plan for Climate Action
PLINIVS	PLINIVS - Centro Studi per l'Ingegneria Vulcanica Sismica e Idrogeologica
PTSE	Periferia Sterias Elladas (Region of Central Greece)
RESILOC	Resilient Europe and Societies by Innovating Local Communities
UNDRR	United Nations office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
VESPA	Rapid Vulnerability Analyses for Practical Application in cities
WP	Work Package

Glossary

Climate impacts	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (including ecosystem services); and infrastructure (based on IPCC, 2018)
Exposure	Exposure is the situation of people, infrastructure, housing, production capacities and other tangible (human) assets located in hazard-prone areas.
Hazard	Hazards have the potential to cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.
Indicator	An indicator is a measurement or value which gives you an idea of what something is like.
Climate Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.
Vulnerability	Vulnerability refers to the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards.

Executive summary (publishable)

The **ClimEmpower Deliverable D2.2 "Climate Change Resilience: indicators"** provides a short overview on resilience, resilience frameworks, and **focuses on available indicators that support the assessment of Climate Change Resilience**. Over the past years, research and emphasize has been given to define suitable indicators, leading to extensive indicator lists. Within this deliverable these are reviewed and a first step towards prioritizing suitable indicators is done.

Within the ClimEmpower scope, D2.2 follows up on the work done within D1.2 "ClimEmpower scenarios" that depicts the targeted regions within ClimEmpower, their needs and current status of resilience. Further, D2.2 builds upon D2.1, that gave an overview on existing data sets relevant for risk and impact assessment within Europe as well as available climate services that provide information and guidance to regions. The first one is relevant since assessing the availability of data sets gives an indication how easy or difficult it is to gather the information needed to quantify the indicators. The latter, (climate services) present insights into communication and application of these, providing a first understanding of the usability and acceptance of indicators by the target groups.

Furthermore, D2.2 offers information to T2.3 and the related deliverable D2.4 "Measures and strategies for increased Climate Change resilience" that aims to depict the indicators most suited for displaying the effectiveness of adaptation measures to increase the regions resilience and thereby support the development of regional strategies. Moreover, D4.3 Regional CC-resilience recommendations v1 incorporates the indicators of D2.2, engaging with the regional stakeholders to identify the most suited ones for developing CC-resilience recommendations. Final aim is to develop user centric applications for climate resilience (WP3), where WP2 and WP4 and therefore the related deliverables provide the methodology and content.

Resilience is a changing concept that is adapting to altered conditions and needs of the regions and the defining institutions. The sectors investigated, target areas defined and related indicators investigated in preparing this deliverable differ between the defining organizations, regions, and projects. Overall, more than 500 indicators were analysed to guarantee a comprehensive understanding of the state-of-the art indicators. The ones selected for potential use in ClimEmpower (Table 2) already focus on the needs of the regions, as defined in D1.2 "ClimEmpower scenarios". In this deliverable, up to 3 indicators per sector are presented in detail, the selection based on previous projects expertise and anticipated applicability to all regions. Fine-tuning and final mapping of indicators to target groups and regional needs will be done within WP4, through the work of engagement and collective elaboration with the participants in the COP. The set of indicators proposed in this deliverable will thus be further refined in WP4 context, to effectively address the needs of the regions and follower regions involved in the project.

1 ClimEmpower summary

ClimEmpower is a Horizon Europe collaborative research project dedicated to addressing the ongoing Climate Crisis in Europe by empowering the regional stakeholders in some of the most vulnerable European regions (Figure 1).

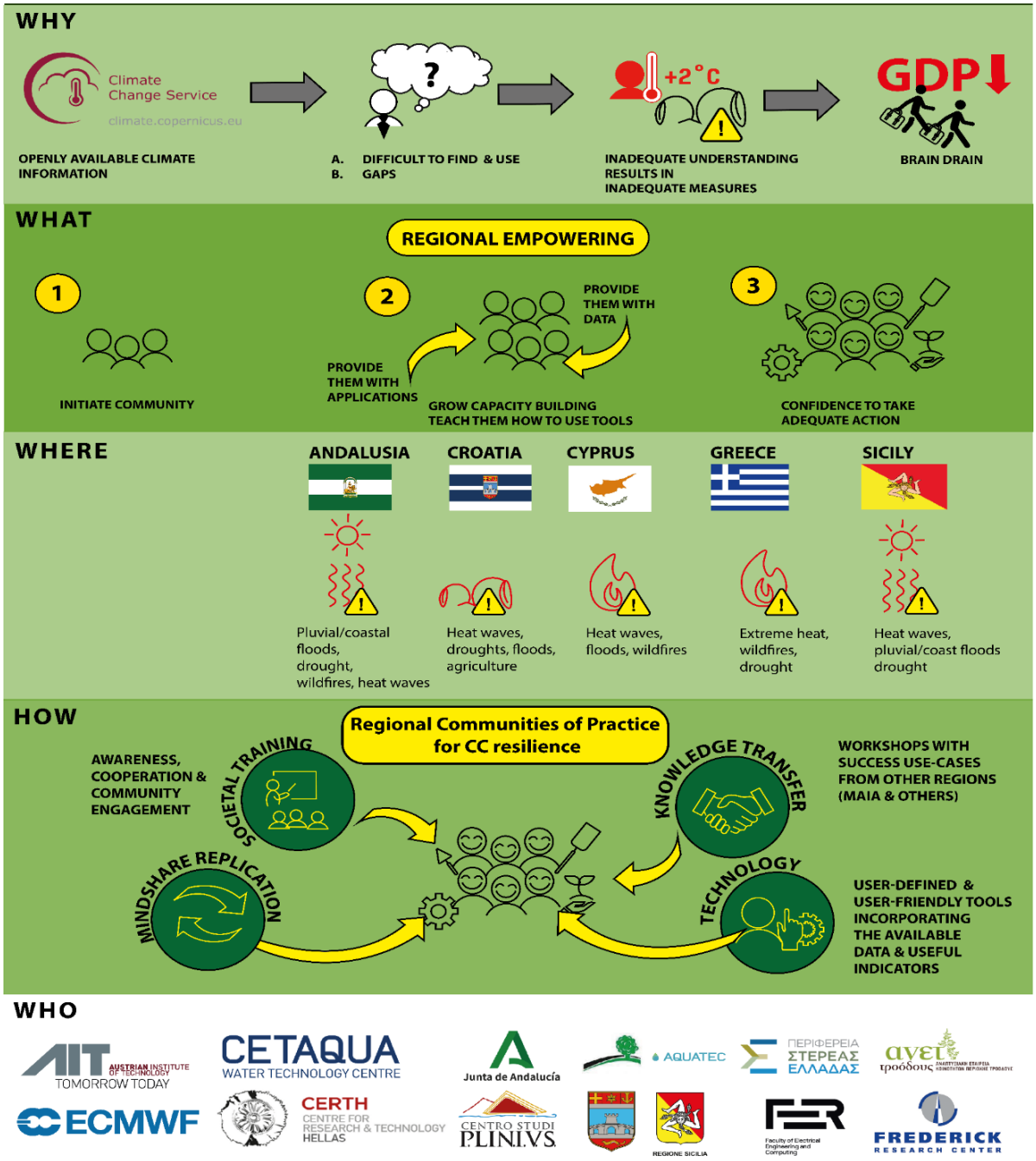

Figure 1: ClimEmpower at a glance: why, what, where, how and who.

1.1 Project Context

Climate risks results from a combination of a hazard, exposure, and vulnerability (REF). Addressing all three aspects is crucial for effective increase of regional resilience. However, exposure, vulnerability, and related aspects, such as adaptive capacity, strongly depend on available knowledge and climate literacy. Consequently, global climate crisis frequently has a higher impact on socioeconomically vulnerable regions, thanks to a higher human and economic potential for addressing the issue in more affluent regions. To maximize its impact, ClimEmpower has therefore chosen to address the EU regions featuring a combination of high potential CC impacts and low and/or stagnant regional GDP/capita. This is mainly the case for regions in South and Southeast Europe (Figure 2).

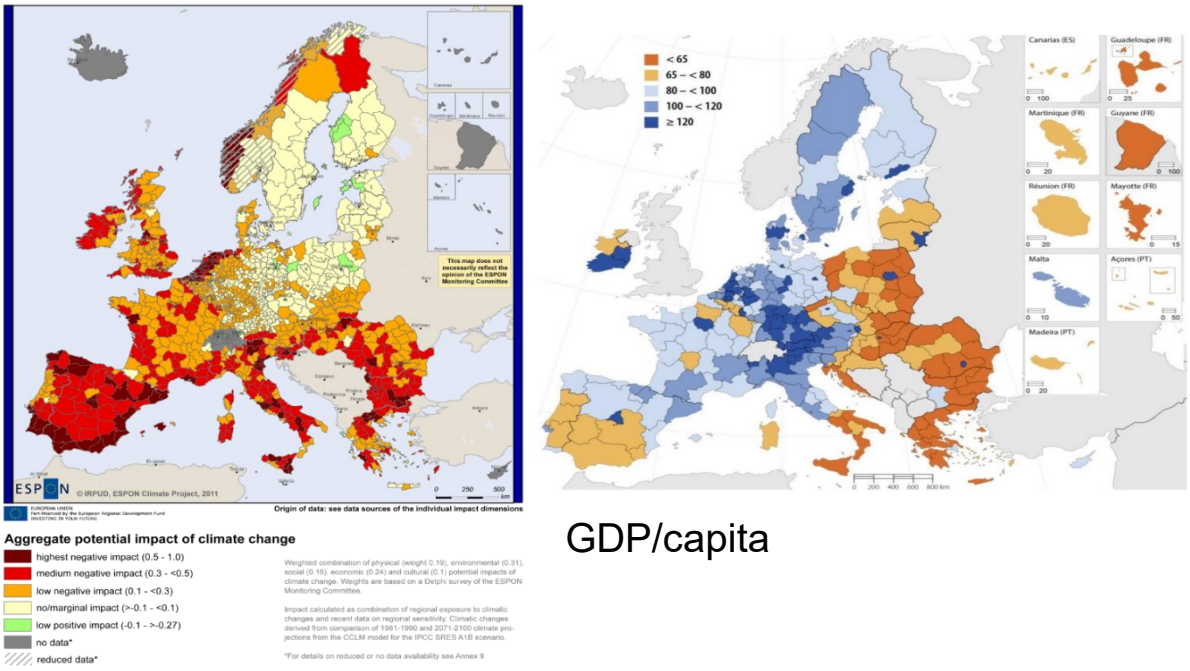

Figure 2: Aggregated potential impact of climate change[2]

The context the project addresses is thus one of an ongoing global warming, high regional vulnerability and low coping capacity of the participating regions, and the **overarching strategic objective of ClimEmpower** is to empower the Regional Authorities (RAs) and other Mission Users (MUs) in five EU-regions featuring a combination of exceptionally high climate hazards and exceptionally low coping capacity by improving their collective understanding of the Climate Change (CC) hazards, risks and resilient development pathways and supporting their knowledge-based regional planning and development through provision of relevant data, knowledge and user-defined and user-friendly decision support applications.

[2] Source: (https://www.espon.eu/climate-2012); GDP/capita (based on https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210303-1

1.2 Project Objectives

To achieve this overarching goal, **ClimEmpower has identified six SMART[3] Strategic Objectives** (**SO**), each one related to one or several work packages. The SOs have also been classified according to different categories: societal, contributing to improved dialogue, awareness, cooperation and community engagement as highlighted by the European Climate Pact (SO1, SO5); scientific, corresponding to research activities for advances beyond the state of the art (SO2, SO3); technological, suggesting and/or developing novel solutions, integrating state-of-the art and digital advances (SO4); and outreach, aimed at sharing ClimEmpower results to a broader scientific and non-scientific audience, including additional regions and communities, to maximize project impact (SO6).

- SO1 Understand regional background, challenges and expectation (WP1, societal)
- SO2 Addressing the gaps in availability and usability of CC data and services (WP2 and WP4, scientific)
- SO3 Identification, definition, estimating, and communication of climate impact/resilience indicators suitable for local end-users (WP2 and WP4, scientific)
- SO4 Simplify access to CC data and development of end user applications (WP3, technological)
- SO5 Empower the regions to activate and enhance their potential for addressing the climate change challenge. (WP4, societal)
- SO6 Ensure the use and impact of the ClimEmpower outputs (WP4 and WP5, scientific and societal)

ClimEmpower's key ambition is to **prove beyond doubt that CC-resilience should, and can, be an integral part of regional development** everywhere in EU and beyond it. That is, we anticipate that the regional stakeholders will recognise that CC-resilient development pathways offer multiple benefits to them, including but not limited to **higher quality of life and reviving economy**, and that these can be understood using available **data, tools, and services**. Second key ambition of the project is to **help the regions address the CC resilience** in key community systems addressed in five ClimEmpower trials.

Underlying philosophy of the project is to "**help the regions to help themselves**". This will be achieved through various mechanisms, including co-creation and mediation of the regional "Communities of Practice", provision of the Climate Change -resilience training materials, as well as in provision and training in use of the user-centric data and services – including those that have already been made available through previous research projects and EU initiatives.

[3] Specific (related to WPs), Measurable (by relevant KPIs), Achievable (the WPs in which they will be achieved are listed), Realistic (since they are referred and explained in the methodology section), and Timebound (each KPI is related to a deliverable and a month of achievement).

2 Introduction

2.1 Deliverable summary

This Deliverable D2.2 is the second deliverable of WP2 “Addressing the CC data and knowledge gaps”. It provides an overview of the resilience framework, its development and importance, gives a definition for resilience and especially focuses on the review and analysis of existing climate change resilience indicators for different sectors (e.g. governance, telecommunications, finance…). The goal of this deliverable is to provide a solid base for T2.3 “Climate impact assessment, adaptation strategies and user-centric services”, WP3 “User-centric CC resilience enhancing services” and WP4 “Empower the regions” since based on the analysed indicators, the most suitable ones can be selected, if needed further developed, and used for setting up climate services to support and empower the regions in their path to climate resilience.

Within the deliverable, first the resilience term is explained, its historical development depicted, and the term defined to ensure a common understanding. Then, the methodological approach and used sources are depicted. A literature review on the application, suitability, barriers, and potentials of indicators was performed, as well as an analysis of indicator lists set-up within reports, (inter-)national projects and norm from the international organization on standardization (ISO) . The indicators were analysed according to different characteristics (see methodology) and a first selection presented within this report was linked to the analysed data sets and climate services (D2.1).

2.2 Results and expected impacts

This deliverable presents an overview of the latest resilience indicators as designed within research projects, scientific papers, and most relevant international organisations. Its goal is to provide a comprehensive base for future work within WP2, WP3 and WP4. Moreover, a first approach to identify relevant indicators was done, that will be expanded on within WP4 as well as T2.3.

The work carried out relates to SO3 "identification, definition, estimating and communication of climate impact/resilience indicators suitable for local end-users" that focuses on analysing the available climate change and impact indicators to be used, tested, and validated by the CoPs (WP4). Additionally, it relates to SO5 „Empower the regions to activate and enhance their potential for addressing the climate change challenge„ as indicators should make the assessment of impacts, possible adaptation measures and strategies more tangible.

D2.2 presents an important step towards EO1 „Increased understanding of climate risks in case study regions“ as it displays possible indicators for assessing climate hazards, exposure, vulnerability (the three components of climate risk assessment) and towards EO3 that focuses on CC-resilient development strategies, which can be based on the indicators analysed and displayed here.

2.3 Relation to other work

The aim of D2.2 is to provide an overview of existing indicators used / suggested to be used for climate resilience assessments. Since the indicators should be usable within the climate services developed in WP3, the main focus is put on indicators that can be quantified,

therefore, it relates to D2.1, which was the first deliverable of WP2. Within D2.1 available data sets and climate services were investigated, collected, and analysed. The data sets are taken up within D2.2 regarding their applicability to compute the collected indicators.

Within WP1 one key outcome was D1.2 "ClimEmpower Scenarios" that depicted shortly the climate risk assessment and resilience framework, as well as a first resilience assessment done by the case studies of ClimEmpower. The indicators related to the used assessment framework are taken up within this deliverable and the accompanying excel list.

Based on the needs of the regions and the collected data sets (D1.2, D2.1) data gaps were identified and potential methods to close those analysed (D2.3). Consequently, the methodologies to provide data stated in D2.3 might be relevant for some of the indicators listed within this report.

As next steps, the relevant indicators found, will be communicated to the CoPs, and used to set up regional CC resilience recommendations (D4.2, WP4) which then, in combination with D2.2, form the base for defining new indicators (if needed) to enable regions to understand and tackle the challenges they are facing. The technical implementation of the selected indicators is performed in WP3.

The interdependencies of WPs and Deliverables is depicted below (Figure 3).

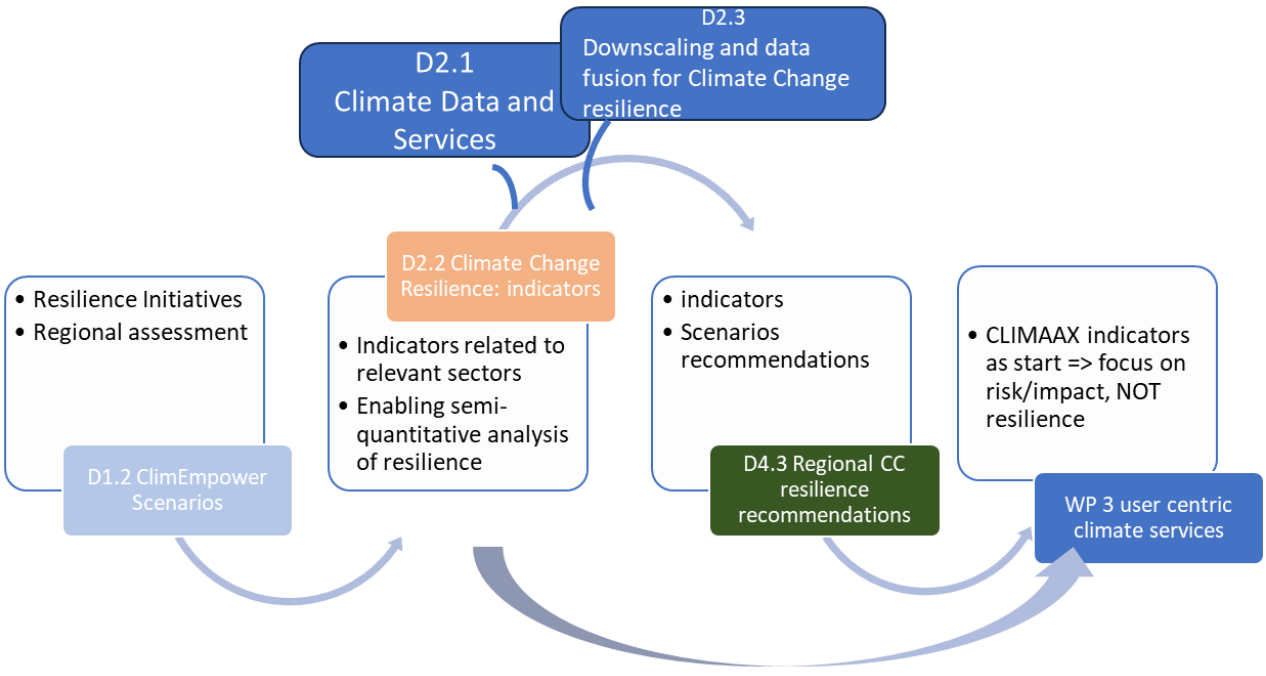

Figure 3: Interdependencies between WPs and Deliverables

2.4 Data, security, and ethics

2.4.1 Data interoperability

Within the deliverable mainly lists of indicators, as provided in pdf format, were used. The indicators were collected within an excel sheet (.xlsx) and are made available via Zenodo: https://doi.org/10.5281/zenodo.14529310.

2.4.2 Data accessibility and reuse:

The ISO Norm needs to be purchased; all other sources are open data.

Table 1: Data used in preparation of ClimEmpower deliverable DX.Y

Data set name	For mat	Siz e	Owner & re-use condition s	Potential Utility within and outside	Unique ID
ISO 37123:2019	PDF	1 MB	ISO norm	Source of resilience indicators	ISO 37123:2019
D3.1 – RESILOC Resilience Indicators	PDF	1,8 MB	RESILOC, CC BY 4.0	Methodology, indicator definitions, examples of proxy functions for estimating the indicators	CORDIS documentIds=080166e5e7dbd6ed&appld=PPGMS
Compilation of Illustrative Targets and Indicators for the Global Goal on Adaptation	PDF	1,2 MB	UNFCCC, Public Domain	Sources of targets and indicators	https://www4.unfccc.int/sites/SubmissionsStaging/Documents/202305311331---United%20Nations%20Foundation.pdf
D2.4 – CLIMAAX Report on integrated risk assessment tools of relevance to the CRA Toolbox	PDF	3,8 MB	Free	Longer text describing methodology	CORDIS documentIds=080166e50ecef8fa&appId=PPGMS

Full list of resilience indicators recommended by ClimEmpower team, as well as the indicator lists found in the reviewed literature from the scientific literature review, as described in Section 4.1 have been published as Open Data on Zenodo.

Table 2: Data produced in preparation of ClimEmpower deliverable D2.2

Data set name	Format	Size	Owner & re-use condition s	Potential Utility within and outside	Unique ID
ClimEmpower list of resilience indicators	.xlsx	524 KB	ClimEmpower, CC BY 4.0	Climate impact/resilience indicators suitable for local end-users	https://doi.org/10.5281/zenodo.14529310.
ClimEmpower literature review resilience indicators	.xlsx	91 KB	ClimEmpower, CC BY 4.0	Sources of information on Climate impact/resilience indicators	https://doi.org/10.5281/zenodo.14529310.

2.4.3 Security and Ethics

The work performed in this deliverable and the data used or produced (if any) aren't considered sensitive in terms of ethics or security.

Potential users of these results are kindly reminded that Climate Change disproportionally impacts affect societally disadvantaged groups and urged to pay special attention to Societal Justice impacts in their CC-resilience assessment and in planning and implementation of the CC-resilience enhancing measures (see also Table 5).

3 Climate Change Resilience

Before detailing the methodological approach of the presented work, the evolution of the resilience concept and some examples of (climate change) resilience frameworks are given to ensure a common understanding.

3.1 Resilience Concept: Origin, Development, and Definitions

Before delving deeper into the concept of resilience, it is necessary to define the term. Resilience (from Latin resilire) means "to spring back" or "to return to the starting point". Resilience thus addresses how systems can return to a particular initial state after it has been disrupted (e.g., by crises, disasters, etc.). A significant contribution to this concept comes from Holling (1973), who, in his work "Resilience and Stability of Ecological Systems," describes that resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist. In this definition resilience is the property of the system and persistence or probability of extinction is the result.

Since 1973 the concept evolved and deviated from “returning to its original state” to “returning to a stable state” emphasizing that there are numerous definitions of (urban) resilience. Meerow et al. (2016), for example, analysed 25 different definitions in their study and concluded that ambiguities prevent a single, unified definition of "(urban) resilience." Given the challenges of defining and characterizing the terms "resilience", as well as the many disciplines involved in this field of research, it is not surprising that multiple definitions exist.

In general, there are three different levels of resilience: engineering, ecological, and evolutionary resilience. The first two are equilibrium-based approaches, while evolutionary resilience encompasses a broader understanding of the term.

3.1.1 Engineering Resilience

The first level of resilience is engineering resilience, which defines resilience from an equilibrium perspective and refers to a system's ability to return to equilibrium or a stationary state after a temporary disruption (Holling, 1973). Such disruptions can include natural disasters like floods and earthquakes, as well as social upheavals like wars, revolutions, or financial crises. This approach is inherently reactive, as the system responds to a disturbance and restores its original state without making changes to its fundamental elements or structures (Newman et al., 2009).

3.1.2 Ecological Resilience

The second level focusses on the equilibrium perspective as well and links the reactive aspect of engineering resilience with the possibility of multiple equilibrium states. Here, necessary measures taken after a disturbance are combined with additional sustainability goals (Kegler, 2016). While engineering resilience considers only one equilibrium state, ecological resilience recognizes multiple equilibrium states to which a system can shift. This broadens the original idea of resilience as "bouncing back" (Davoudi, 2012) by incorporating self-renewal capabilities. This level of resilience refers strongly to C.S. Holling (1973) and later Berkes and Folke 1998, Berkes et al. 2003 and Carpenter et al. 2005.

3.1.3 Evolutionary Resilience

The third level, evolutionary resilience, includes the criteria of engineering and ecological resilience but further incorporates the ability for strategic transformation and adaptability to disturbances (Kegler, 2016). The most significant difference from the other levels is that resilience is no longer viewed as a static state or a balance to be maintained or achieved. Instead, it is seen as an ongoing process of learning and development (Kegler, 2014). This perspective acknowledges that systems are flexible and can evolve over time independently of external disturbances or linear cause-effect relationships (Scheffer, 2009; Davoudi, 2012).

		Equilibrium perspective	Evolutionary perspective
Basic concept		Emphasises the return to a single previous state or equilibrium following a shock or the shift to alternative multiple equilibria	Emphasises the capacity of a system to adapt and fundamentally change in the face of numerous shocks and disturbances
Definitional elements		Bouncing back Absorbing shocks	Positive adaptability/bouncing forward System transformation
Main fields of use		Engineering, ecology (re absorbing shocks), economics (mainstream)	Psychology, socio-ecological systems, economics (evolutionary, ecological)
The resilience of what? (Entity or system that needs to be resilient)		Resilience studies cover a broad range of disciplines and levels. In economic systems, the unit of analysis can be people, firms, communities, regions, countries	
		Tends to take a fairly narrow view eg regional employment	Tends to take a systems view eg ecological systems, regional economic systems
To what? (Nature of shock or disturbance)		Resilience studies cover a broad range of different shocks, disturbances and perturbations	
		Examines a single shock eg recession Tends to view shocks in a negative light	Examines multiple shocks, disturbances and long-term trends eg climate change Tends to view shocks as a learning opportunity
By what means? (Resilience strategies)		Resilience strategies tend to be context-specific, although some cover a range of contexts – variety, dispersity, redundancy and optionality	
		Risk mitigation, impact absorption, recovery	Resilience is a long-term *process* including ongoing adaptation and learning
With what outcome? (Outcomes from resilience)		Return to the original pre-shock state – the system structure and function are unchanged Avoiding the shock altogether	Long-run performance or health of the system (which needs to be defined) – the system structure and even function may change The survival of the system
Relation-ship with other concepts	Closely-related concepts	Risk management Robustness	Antifragility Complex adaptive systems
	Sustainability	Not much to say on this	Generally seen as positively related
	Productivity	Short-term trade-off, via mechanisms like redundancy, variety and dispersity	In the long term, the relationship is more complex via mechanisms like innovation
	Inclusion	Greater equity and social connections may increase community resilience	
Measurement approaches		Approaches that focus on single shocks Indicators of time to recovery and avoidance of losses, and models of how long it takes for a shock to dissipate, or where a system would have been in the absence of a shock	Approaches that take a long-term, systemic view System dynamic models, case studies, mixed methods, indicator frameworks, and other methods to gain a broad picture of system performance in the long term

Figure 4: Resilience Perspectives, Source: Pells, S. (2023). Resilience–definitions, concepts and measurement: a literature review.

3.1.4 The Resilience Concept as a Connecting Element

A distinctive strength of the resilience concept is its ability to act as a "bridging concept" (Beichler et al., 2014) facilitating connections between different fields of knowledge and fostering multidisciplinary dialogue. A bridging concept resonates with various social domains and enables scientific collaboration across disciplines (Meerow & Newell, 2016). This is achievable because the meaning of such a concept or object has a flexible structure, allowing it to adapt to the diverse needs of individual disciplines and stakeholders. As Vale (2014, p. 198) notes, this flexibility represents one of the greatest advantages of resilience:

> *"The biggest upside to resilience, however, is the opportunity to turn its flexibility to full advantage by taking seriously the actual interconnections among various domains that have embraced the same terminology."*

However, this flexibility also introduces challenges. Ambiguities in the concept make it more difficult to operationalize resilience effectively (Meerow & Newell, 2016). That´s because its flexibility and adaptability to different disciplines and contexts lead to ambiguities in definition and scope. These ambiguities make it difficult to establish clear metrics, standardized methodologies, or universally applicable strategies for implementation. Additionally, the interdisciplinary nature of resilience requires integrating diverse perspectives and priorities, which can complicate coordinated action.

3.1.5 Resilience in Urban and Spatial Planning

In the field of urban and spatial planning, the concept of resilience is described in academic discourse as a "conceptual umbrella." Despite the lack of a unified definition, it offers a promising perspective for planning practices. As previously noted, this duality represents both the strength and the limitation of the concept, which can be employed to develop spatial strategies for adaptation, mitigation, and transformation of systems (Pickett et al., 2004; Brunetta & Salata, 2019).

Davoudi's (2012) definition of evolutionary resilience - where the dynamic disequilibrium of a system fosters robustness, adaptation, transformation, and learning to generate knowledge and intelligence (Folke et al., 2010) - has significant implications for urban planning. It positions resilience as a normative concept for territorial systems, potentially forming a new approach to spatial development (Brunetta & Salata, 2019).

Given the continuous and unpredictable nature of change, spatial resilience also implies that territorial systems must continuously adapt and self-organize to remain functional (Brunetta & Caldarice, 2020). In cities and regions, the degree of self-organisation is heavily influenced by the availability of information, communication, and effective management. Achieving this balance requires both freedom and room for experimentation, alongside structured governance, and hierarchy. When governance systems are well-organized and interconnected, subsystems can largely function autonomously and can self-regulate, maintain, and adapt as needed. Thus, a key enabler of self-organization is a governance framework that coordinates and supports the efficient operation of subsystems while allowing decentralized, localized, and small-scale initiatives to flourish. Functioning community networks are particularly important in fostering self-organization and enhancing community resilience.

Key elements that support self-organisation include: Economic factors regarding equitable resource distribution and a diversity of economic resources; Information and communication for providing trusted narratives and reliable sources of information; Social capital built through strong social ties and networks, citizen participation, effective leadership, trust, reciprocity, and attachment to place; Community competencies gained through collective action, empowerment, and a shared sense of community. (Korosteleva & Petrova, 2022; Norris et al., 2008; Berkes & Ross 2013).

Since self-organisation is a core aspect of resilience, it must be incorporated into the resilience indicator-set as well. Examples of indicators reflecting a region´s capability for self-organization include early warning systems or educational trainings (as stated in the indicators list on zenodo).

3.1.6 Resilience in Climate Change Mitigation and Adaptation context

Intergovernmental Panel on Climate Change (IPCC, AR6 WGII SP) defines resilience as:

> *"The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions."*

and notes that:

> *"The term describes not just the ability to maintain essential function, identity and structure, but also the capacity for transformation." (IPCC AR6, WGII SP)*

This definition refers strongly to the definition of C.S. Holling (1973) and later Berkes and Folke 1998, Berkes et al. 2003 and Carpenter et al. 2005 on socio-ecological resilience as well as the definition of evolutionary resilience by Davoudi (2012) and coincides with the evolutionary perspective. At the same time, the growing system´s complexity has transformed the purpose and need for resilience indicators. They have evolved into essential instruments for decision support in adaptation and transformation management.

3.1.7 Conclusion

The resilience concept has evolved into a multifaceted framework that bridges disciplines and adapts to diverse contexts, offering a valuable tool for addressing complex challenges like climate change and urban/regional planning. Its progression from static equilibrium models to dynamic, evolutionary perspectives reflects an increasing emphasis on adaptability, transformation, and learning. However, the flexibility that makes resilience a robust conceptual tool also introduces challenges, including definitional ambiguities and difficulties in operationalizing standardized metrics or strategies. Despite these challenges, resilience remains a critical framework for fostering sustainability, adaptability, and interconnection in socio-ecological and urban systems.

To minimise the chance of misunderstanding within the scope of Climate Change adaptation and mitigation, ClimEmpower team shall utilise the resilience definition of the Intergovernmental Panel on Climate Change (IPCC, AR6 WGII SP) in all of its work.

3.2 The Conceptual Framework & Resilience Indicators:

3.2.1 Conceptual Framework

Due to the different definitions of resilience and its application in different scientific disciplines, there are also different conceptual frameworks. A comprehensive framework that we would like to draw on is the one developed by Arup with support from the Rockefeller Foundation, based on extensive research in cities. It offers a framework for understanding the complexity of cities and the factors that shape their resilience. By examining these factors, cities can evaluate their level of resilience, pinpoint critical vulnerabilities, and identify targeted actions and initiatives to strengthen their resilience. While initially designed for cities, the framework is highly transferable to regions. Like cities, regions are complex systems shaped by interconnected social, economic, and environmental factors. Applying this framework to regions allows for an evaluation of regional resilience by identifying critical vulnerabilities, assessing interdependencies across sectors and communities, and targeting specific actions to enhance adaptive capacity. By addressing the unique characteristics and challenges of regions—such as rural-urban dynamics, resource distribution, and governance structures—the framework provides a comprehensive approach to strengthening resilience at a broader geographic scale.

The Framework developed by Arup contains four dimensions with 12 drivers/goals and 52 indicators based on seven qualities. The four Dimensions of resilience a city or region relates to are: Health & Wellbeing, Economy & Society, Infrastructure & Environment and Leadership & Strategy (Table 3).

Table 3: Dimensions of Resilience, Source: Da Silva, J. (2013). City resilience index: understanding and measuring city resilience. New York City: Rockefeller Foundation (Arup International Development).

Dimension	Driver
Health & Wellbeing	1. Meets Basic Needs: Provision of essential resources required to meet a person's basic physiological needs.
	2. Supports Livelihoods and Employment: Livelihood opportunities & support that enable people to secure their basic needs. Opportunities might include jobs, skills training, or responsible grants & loans.
	3. Ensures Public Health Services: Integrated health facilities & services, & responsive emergency services. Includes physical & mental health, health monitoring & awareness of healthy living & sanitation.
Economy & Society	4. Promotes Cohesive and Engaged Communities: Community engagement, social networks & integration. These reinforce collective ability to improve the community & require processes that encourage civic engagement in planning & decision-making.
	5. Ensures Social Stability, Security and Justice: Law enforcement, crime prevention, justice, & emergency management.
	6. Fosters Economic Prosperity: While Driver 2 is about individual livelihoods, Driver 6 is about the economy on a wider scale. Important economic factors include contingency planning, sound management of city finances, the ability to attract business investment, a diverse economic profile & wider linkages.
Infrastructure & Environment	7. Enhances and Provides Protective Natural & Man-Made Assets: Environmental stewardship, appropriate infrastructure, effective land use planning & enforcing regulations. Conservation of environmental assets preserves the natural protection afforded to cities by ecosystems.
	8. Ensures Continuity of Critical Services: Diversity of provision, redundancy, active management & maintenance of ecosystems & infrastructure, & contingency planning
	9. Provides Reliable Communication and Mobility: Diverse & affordable multi-modal transport networks & systems, ICT & contingency planning. Transport includes the network (roads, rail, signs, signals etc.), public transport options & logistics (ports, airports, freight lines etc.)
Leadership & Strategy	10. Promotes Leadership and Effective Management: Relating to government, business & civil society. This is recognisable in trusted individuals, multi-stakeholder consultation, & evidence-based decision-making.
	11. Empowers a Broad Range of Stakeholders: Education for all, access to up-to-date information, & knowledge to enable people & organizations to take appropriate action. Along with education & awareness communication is needed to ensure that knowledge is transferred between stakeholders & between cities.
	12. Fosters Long-Term and Integrated Planning: Holistic vision, informed by data. Strategies/plans should be integrated across sectors & land-use plans should consider & include different departments, users & uses. Building codes should create safety & remove negative impacts.

The indicators also integrate seven qualities of resilient systems (Figure 5):

- **Reflectiveness** involves learning from past experiences to inform future decisions, adapting standards and behaviors as circumstances evolve. For example, reflective planning processes can better respond to dynamic challenges.
- **Resourcefulness** is the ability to identify alternative ways to utilize resources during crises to meet needs or achieve goals. For instance, households in Chile's Central Valley maintain wells as a backup for water supply during earthquakes when municipal services are disrupted.
- **Robustness** ensures systems are well-designed, constructed, and managed to withstand shocks without catastrophic failure. For example, robust infrastructure may fail safely even when design thresholds are exceeded.
- **Redundancy** involves creating spare capacity and diversity to handle disruptions or surges in demand. For instance, energy systems with multiple delivery pathways can adapt to sudden changes in supply or demand.

- **Flexibility** emphasizes adaptability, enabling alternative strategies in response to crises. Cities can enhance flexibility through innovative technologies or traditional practices, such as using public buses for emergency evacuations during disasters.
- **Inclusivity** ensures broad consultation and shared ownership in decision-making, prioritizing the needs of vulnerable groups. For example, inclusive early warning systems ensure that everyone at risk receives timely information to minimize harm.
- **Integration** promotes collaboration across systems and institutions, enabling shared resources and coordinated efforts. Integrated city plans, for instance, address multidisciplinary issues like climate change, disaster risk reduction, and emergency response through unified strategies.

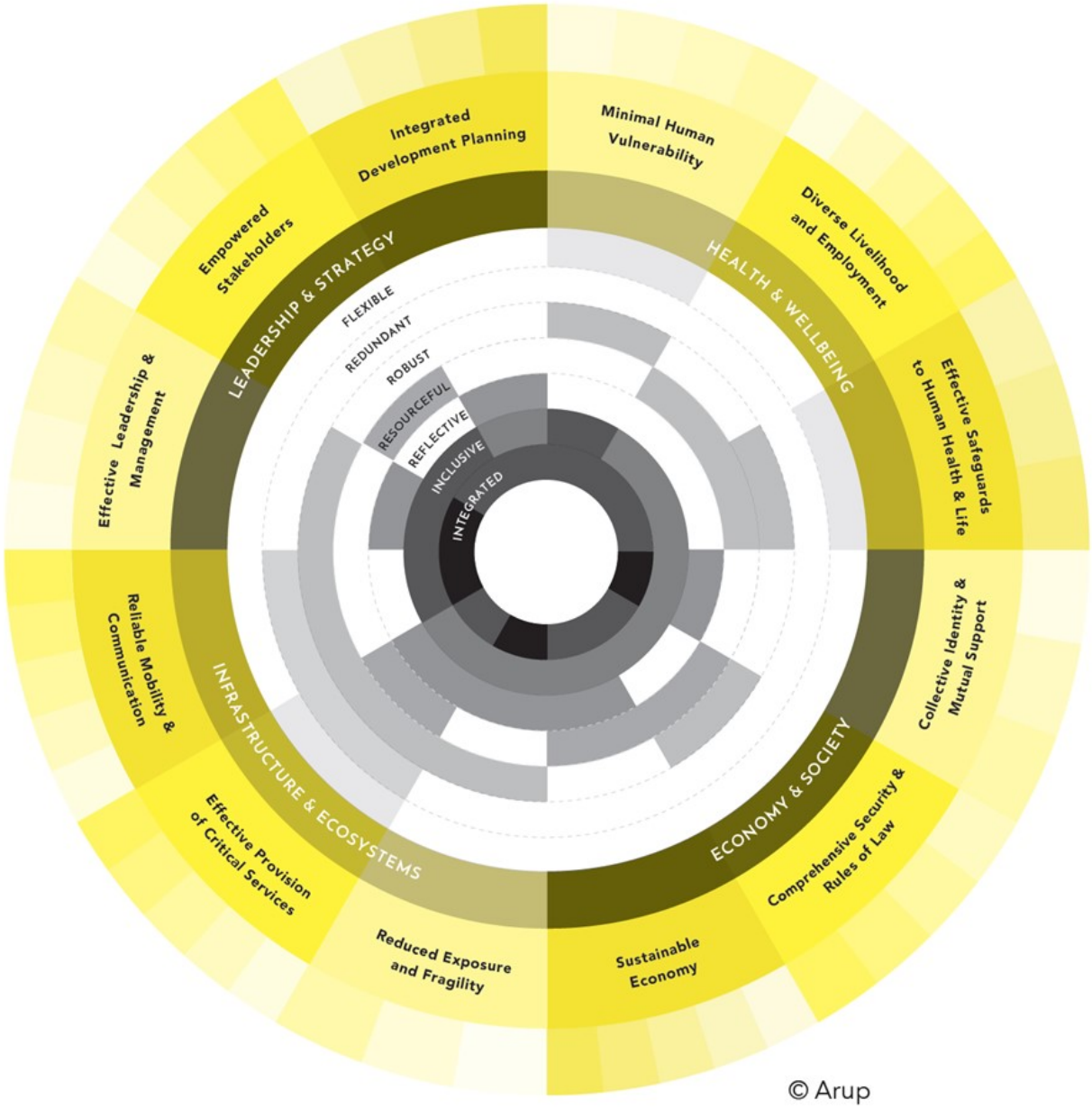

Figure 5: Conceptual Framework, Source: Da Silva, J. (2013). City resilience index: understanding and measuring city resilience. New York City: Rockefeller Foundation (Arup International Development)

Various global organizations also define and apply climate resilience frameworks, which differ depending on the organizations' background and emphasise. Within this deliverable we focused on resilience definitions of the Intergovernmental Panel on Climate Change (IPCC), the United Nations Office for Disaster Risk Reduction (UNDRR) and the United Nations Framework Convention on Climate Change (UNFCCC). Within Table 4 the three frameworks of these organisations, with their dimensions/focus, topics, and key factors are described to display the differences that are also reflected in the indicators (collected within the ClimEmpower_indicators.xlsx file). They differ slightly from the above-mentioned Arup framework depicting the impact of the organisational focus on the framework's definition.

IPCC (Intergovernmental Panel on Climate Change)

The IPCC is the leading scientific body responsible for assessing the science related to climate change. It provides policymakers with regular scientific assessments, projections, and recommendations regarding climate risks, mitigation, and adaptation strategies. In terms of climate resilience, the IPCC outlines frameworks, and pathways for integrating adaptation, sustainable development, and mitigation to build resilience at the local, regional, and global levels. Its reports, such as the AR6, are critical in shaping climate policies worldwide.

UNDRR (United Nations Office for Disaster Risk Reduction)

UNDRR leads efforts to reduce disaster risks and enhance global resilience against natural and climate-induced disasters. It promotes frameworks like the Sendai Framework for Disaster Risk Reduction, which emphasizes preparedness, early warning systems, and resilience-building in the face of climate change. UNDRR works with governments, communities, and stakeholders to ensure sustainable development aligns with risk reduction measures.

UNFCCC (United Nations Framework Convention on Climate Change)

The UNFCCC is a treaty framework established to combat climate change by stabilizing greenhouse gas concentrations in the atmosphere. It facilitates global cooperation through initiatives like the Paris Agreement, which sets targets for climate mitigation and adaptation. The UNFCCC supports resilience-building through climate financing mechanisms, adaptation programs, and international negotiations aimed at addressing climate vulnerabilities and promoting sustainable development.

	IPCC - Climate Resilient Development Solution Framework	**UNDRR / Sendai Framework for DRR**	**UNFCCC - Framework for the global goal on adaptation**
Dimensions / Focus	• Interconnected Actions • Diverse Knowledge Systems • Urgency of Action • Inclusive Planning • Alignment with SDGs	• Understanding disaster risk • Strengthening disaster risk governance to manage disaster risk • Investing in disaster risk reduction for resilience • Enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation and reconstruction.	• Impact, Vulnerability and Risk Assessment • Planning • Implementation • Monitoring, Evaluation and Learning • Finance, Capacity Building, and Technology Transfer •

Themes	• Mitigation and Adaptation • Systems Approach • Knowledge Integration • Capacity Building • Timeliness • Immediate Implementation • Stakeholder Engagement • Equity Considerations • Sustainable Development Goals (SDGs) • Co-benefits	• **Understanding Disaster Risk** • Improve risk assessment and analysis. • Enhance knowledge of disaster risk • Integrate disaster risk information into development planning. • Strengthening Disaster Risk Governance • Establish and strengthen disaster risk governance structures. • Ensure accountability and transparency in disaster risk management. • Promote stakeholder engagement and participation. • **Investing in Disaster Risk Reduction** • Allocate resources for disaster risk reduction initiatives. • Enhance the resilience of critical infrastructure and services. • Foster innovation and technology for disaster risk reduction. • **Enhancing Disaster Preparedness** • Strengthen disaster preparedness and response capabilities. • Promote community-based disaster preparedness initiatives. • Ensure continuity of essential services during disasters. •	• **Health and Wellbeing** • including food, water, health, cultural heritage, society • **Infrastructure** • including cities, settlements, key infrastructure, energy and industrial infrastructure • **Economy and Workers** • including poverty and livelihoods, mobility and migration • **Nature and Biodiversity** • including terrestrial and freshwater ecosystems, oceans and coastal ecosystems, mountain regions, polar regions and biodiversity
Key Factors / Targets	• Implement renewable energy solutions alongside adaptation measures. • Develop cross-sectoral policies that address multiple objectives. • Engage local communities and Indigenous peoples in planning processes.	• **Understanding Disaster Risk** • Collect and analyze data on hazards, vulnerabilities, and exposure. • Promote education and awareness on disaster risk reduction. • Use risk information to inform policies and decision-making.	• **Impact, Vulnerability and Risk Assessment** • Assessment of climate impacts on ecosystems and communities • Identification of vulnerable populations and ecosystems • Risk and vulnerability assessments that account for transboundary climate risks.

	• Provide training and resources for local adaptation initiatives. • Set and adhere to ambitious climate targets and timelines. • Fast-track funding for urgent adaptation projects. • Conduct participatory workshops to gather input from affected communities. • Design policies that prioritize support for marginalized groups. • Integrate climate considerations into national and local development plans. • Promote green jobs and sustainable livelihoods through climate initiatives.	• Strengthening Disaster Risk Governance • Create national and local platforms for disaster risk reduction. • Foster collaboration among stakeholders, including government, private sector, and civil society. • Involve communities in decision-making processes related to disaster risk management. • **Investing in Disaster Risk Reduction** • Mobilize risk-sensitive investments to avoid creating new risks. • Invest in sustainable development practices that reduce vulnerability. • Encourage research and development in disaster risk management tools and techniques. • **Enhancing Disaster Preparedness** • Develop and implement effective early warning systems. • Train communities in disaster response and recovery strategies. • Establish contingency plans and conduct regular drills and simulations. •	• **Planning** • Development of national policy instruments for climate adaptation • Integration of adaptation strategies into development plans • Incorporation of climate change impact projections into infrastructure investments • **Implementation** • Execution of adaptation actions in line with international frameworks (e.g., Sendai Framework) • Local adaptation initiatives and community engagement • Incorporation of ocean acidification indicators • **Monitoring, Evaluation and Learning** • Establishment of metrics for tracking progress • Evaluation of adaptation effectiveness and learning from outcomes • Continuous updating of national climate change risk assessments • **Finance, Capacity Building and Technology Transfer** • Access to financial resources (e.g., GEF, GCF) • Capacity building for financial management and project implementation • Recognition of support for technology transfer

Table 4: summary of resilience framework characteristics of IPCC, UNDRR and UNFCC

3.2.2 Resilience Indicators

The development and applicability of resilience indicators profited from key organizations like the IPCC, UNFCC, UNDRR or the World Bank that played crucial roles in advancing indicator development, pushing for more comprehensive and nuanced ways of understanding climate vulnerability and adaptive capacity. Technological advancements in computational modelling, satellite imaging, and data analytics dramatically expanded the capabilities of resilience indicators, enabling more precise, dynamic, and predictive assessments. The contemporary approach emphasizes interdisciplinary collaboration, context-specific design, and adaptive frameworks that can capture the intricate interactions between human and natural systems. From basic environmental tracking to complex, real-time adaptive indicator networks, the

evolution reflects a growing recognition of climate change's multifaceted challenges and the need for sophisticated, integrated approaches to understanding and managing climate risks.

In general, the aforementioned organizations stress that **resilience indicators should be: Context-specific, Measurable, Comparable, Actionable, and Aligned with local and national development goals.**

These characteristics of indicators represent well the ClimEmpower approach and are therefore kept in mind for the selection of the most relevant indicators.

3.2.3 Common Understanding of Resilience and its Connex to ClimEmpower

Common Themes Across frameworks and their representation within ClimEmpower:

- **Holistic approach to resilience**: within ClimEmpower a systemic and inter-sectoral view foreseen to ensure the comprehensive analysis of suitable indicators and ensure the understanding of interactions by the local stakeholders. This is achieved by providing educational material (WP4) and organizing tematic workshops, integrating different sectors within the climate impact assessment and adaptation strategies (T2.3) and their implementation within the climate services (WP3).
- **Emphasis on measurable, actionable indicators**: the collected indicators were characterised to include whether they are qualitative or quantitative and, for the latter, the difficulty of the needed data. This approach provides a first step towards measurable indicators. Furthermore, to ensure that they are actionable, the indicators will be discussed with local stakeholders.
- **Focus on adaptive capacity**: by incorporating sectors such as economics, governance, education, telecommunication, Social and Population including indicators such as "*percentage of neighbourhoods with regular and open neighbourhood association meetings*" the adaptive capacity of a region, or city is assessed and can be monitored.
- **Recognition of local and regional variations**: the selection of the ClimEmpower regions was done to cover different geographical, cultural aspects, climate hazards and vulnerabilities. Within the first year of the project the differences and commonalities within the regions were identified and will be considered in the selection of relevant indicators.
- **Need for dynamic, evolving indicator frameworks**: within ClimEmpower we decide on one framework and indicators, acknowledging the need for dynamic ones by incorporating the possibility of adapting the indicators and related sectors within the developed Climate services (WP3).

Summarizing, the identification, development and characterization of indicators is an ongoing process which reacts to changing conditions. Nevertheless, specific characteristics and approaches are crucial to ensure the applicability and usefulness of climate resilience indicators.

4 Methodological Approach

For assessing and collecting the state-of-the-art resilience indicators within D2.2, two different steps were taken. First, a literature review to investigate how indicators, their applicability and recommendations are perceived from the scientific community. Furthermore, emphasize was put on literature related to indicators applied to our regions of interest (urban, regional, agriculture). As a second step indicators from the aforementioned organizations, relevant research projects and applicable scientific papers were collected.

4.1 Scientific Literature Research

The goal of the literature research was to find the reasoning why certain indicators were favoured or used instead of others in scientific studies and if there are commonly agreed on indicator sets, that appear in numerous peer-reviewed literature.

To tackle this task, scientific literature with focus on urban, regional, and agricultural-related resilience indicators – based on the characteristics of the ClimEmpower regions - was performed using the snowball system (starting from specific literature and key words to investigate / review potentially important papers). It is important to note that it is not part of ClimEmpower to conduct an extensive literature review on climate resilience indicators. Rather, the literature was used for defining the keywords for characterising/analysing the found indicators and to provide an overview on the scientific approach on climate change resilience indicators.

The following key words for finding the most relevant literature were used:

- Climate
- Resilience
- Indicator
- Regional
- Composite
- Urban
- Agricultural
- Climate Change
- Adaptation

Additionally, an open AI tool called elicit (https://elicit.com/) was used to get a first overview of existing studies on these topics and to synthesize the findings.

4.2 Analysis of existing indicator sets

The indicators analysed where based on the following sources:

- ISO 37123 (4.2.1),
- United Nations Foundation: Compilation of Illustrative Targets and Indicators for the Global Goal on Adaptation (4.2.2),

- The Resilient Europe and Societies by Innovating Local Communities - RESILOC Project (4.2.3)
- CLIMAte risk and vulnerability Assessment framework and toolbox - CLIMAAX project (4.2.4)
- Andalusian Plan for Climate Action (PAAC, 4.2.5),
- VESPA Project and various scientific papers (4.2.6)

The short descriptions of the reports and projects are given below.

4.2.1 ISO 37123: 2019 Sustainable cities and communities — Indicators for resilient cities

The International Organization for Standardization (ISO) is a global federation comprising national standards bodies that collaboratively develop international standards through technical committees. Each ISO member body with interest in a specific subject can participate in the relevant technical committee, ensuring comprehensive and inclusive standard development.

The ISO 37123 was set-up to provide standardized indicators for measuring city resilience. A resilient city is defined as one capable of preparing for, recovering from, and adapting to various shocks and stresses, including natural disasters, pandemics, economic crises, and ongoing challenges like environmental degradation and social inequality. These indicators aim to help cities track their performance, learn from each other, and develop comprehensive resilience strategies by allowing comparisons across different performance measures. The standard supports global sustainability agreements such as the Sendai Framework for Disaster Risk Reduction, the New Urban Agenda, and the UN Sustainable Development Goals, emphasizing that resilience is a core component of sustainable development. While the document provides a framework for measuring resilience, it does not set specific numerical targets, acknowledging that cities may not have direct control over all factors influencing these indicators. The standard is designed to be implemented alongside ISO 37120 and offers a flexible approach to understanding and enhancing urban resilience.

Even though the focus of the ISO is on cities, most/all indicators can be used for assessing regional climate resilience, as is the scope of ClimEmpower.

Within the ISO 37123:2019 the indicators were assigned to 18 sectors. Since the ISO displays an international norm, we followed these sectors and assigned the indicators from the other sources accordingly. The only exception being the category „Climate Change" that we targeted specifically but which is part of „environmental" within the ISO norm.

4.2.2 United Nations Foundation: Compilation of Illustrative Targets and Indicators for the Global Goal on Adaptation

UN Foundation, in partnership with other organisations[4], (UN Foundation, 2023) created the 'Compilation of Illustrative Targets and Indicators for the Global Goal on Adaptation' report. This document outlines a range of indicators designed to measure progress towards the Global Goal on Adaptation (GGA) and to assess the effectiveness of adaptation strategies. The indicators list is a collection of existing indicators from various international agreements and initiatives. Although the main focus is on global scale, the authors acknowledge the need for reflecting local priorities and conditions. The indicators were categorized across five dimensions of the adaptation cycle: 1) impact, vulnerability and risk assessment, 2) planning, 3) implementation, 4) monitoring, evaluation, and learning, and 5) recognizing support in terms of finance capacity building and technology transfer. They aim to provide both quantitative and qualitative metrics that capture the contextual richness of adaptation efforts, ensuring that they are grounded in local realities. In general, the indicators stated partly fit well to other sources and the focus of ClimEmpower, some however are, as stated above, are on the global level, thus not suitable for the regional focus.

UNFCCC builds upon different sources, for instance indicators related to risk are IPCC Working Group 2 Report (IPCC, 2022), IPCC Global to Regional Atlas (IPCC, 2022), and IPCC 6th Assessment (IPCC, 2022).

4.2.3 RESILOC Project

The Resilient Europe and Societies by Innovating Local Communities (RESILOC) project, funded by the European Union's Horizon 2020 research and innovation programme, aims to enhance local communities' preparedness for various hazards, whether planned or unexpected. By integrating local community knowledge with the strategies and support of national and supra-national entities, the project seeks to redefine and increase the community resilience.

The deliverable 3.1 in the document "D3.1 – RESILOC Resilience Indicators" provides a framework, a methodology and tools to enable communities to self-assess their resilience 'assets' and to support them to develop strategies to increase their resilience going forward. The cornerstone of this analysis is a set of 'indicators', and associated 'proxies', to measure community resilience. The 'indicators' are general descriptions of important factors contributing to resilience, while the 'proxies' are more precise and concrete examples. For this reason, within D2.2 proxies are included as indicators. The document "D3.1 – RESILOC Resilience Indicators" contains a total of 70 indicators and 260 associated proxy measures across 6 resilience dimensions: Disaster Risk Reduction (DRR), Economic, Environmental, Governance, Infrastructure, and Social. These dimensions are mapped onto the ones applied within ClimEmpower. Within RESILOC the indicators were developed and then validated through desk research, involving a round of focused literature reviews and an assessment of

[4] Adaptation Research Alliance, Adaptation Without Borders, Alliance for Global Water Adaptation, Argentina 1.5, the Climate Policy Institute, the International Center for Integrated Mountain Development, the International Alliance to Combat Ocean Acidification, and the World Resources Institute

the quality of the indicators using a set of Measurement Quality Criteria. The development of the indicators' list is based on 40 studies, projects, and tools in the last 20 years, from 2000 to 2020, among which the aforementioned ISO. They were chosen because of their focus on modelling, measuring, or visualising community resilience. Only English full-text publications or descriptions were used. The full list, which uses literature sources focusing on general resilience aspects rather than regional ones, is in the section "Appendix B: Literature Review" of the document. The indicators and proxies provide in some cases numerical assessment values, although none of them sets specific numerical targets to quantify the considered measurement.

The whole indicators' list does not contain regional or country-specific peculiarities and is therefore applicable to any of the regions considered in ClimEmpower.

4.2.4 CLIMAAX project

CLIMAte risk and vulnerability Assessment framework and toolboX (CLIMAAX) is a 4-year Horizon Europe project that will provide financial, analytical, and practical support to improve regional climate and emergency risk management plans. CLIMAAX is designed to contribute to the harmonization and consolidation of the practice of climate risk assessment, leaving a legacy for upcoming European initiatives. The project started in January 2023 and runs until December 2026.

Since the developed toolbox is analysed and (partly) used within WP3, the deliverable "D2.4 – Report on integrated risk assessment tools of relevance to the CRA" was analysed for the prevailing report with respect to indicators. The objective of D2.4 is to contribute with Climate Risk Assessment (CRA) methods to the CLIMAAX Toolbox. The toolbox integrates the components of risk (Hazard, Exposure, Vulnerability) into an integral risk assessment and visualizes risk information to develop regional risk profiles, thus, the indicators stated relate to these risk components.

4.2.5 Andalusian Plan for Climate Action

In ANDALUS Region, the Junta de Andalucía published in November 2023 a climate risk assessment methodology to evaluate a list of climate impacts at regional scale. The procedure is divided into two phases: participative and operational. It is based on the Vulnerability Sourcebook Modules (Menk et al., 2022). The main objective is to reduce the risk of Climate Change impacts minimizing their effects and it is fully aligned with the most important and relevant strategic plans at international, European, and national level (IPCC Panel (AR6), EUCRA, ClimateADAPT, etc.).

The Andalusian methodology for climate risk assessment analysis different climate impacts depending on risk evaluation in different strategic areas/sectors: Water resources, agriculture, health, tourism, biodiversity, and ecosystem services, etc. It identifies several impacts related to each of the strategic areas and among them are the floods (pluvial & fluvial, storm surges and sea-level rise), forest fires, droughts (changes in water resources availability and quantity) and heatwaves. Key components of Andalusian climate resilience framework are summarised in Table 5.

Table 5: Key components of climate resilience definitions as used within the Andalus Framework. Source: Updated from Schaefer et al. (2020) and stated in D1.2 "ClimEmpower Scenarios"

Acronym	Explanation	Specific question for the region
R	Robustness and adaptiveness to climate related stresses and shocks	What is the degree of robustness and adaptiveness to climate related stress and shocks in your region?
E	Evaluation and Monitoring: resilience as a process	Is there some public methodology to easily assess climate-related risks and identify potential adaptation measures?
S	Scale (Countries, Regions, Cities, Neighbourhoods, Individual)	What is the level of spatial disaggregation of climate related risks?
I	Interdisciplinarity: resilience as umbrella for different sectors	Are all the critical sectors involved in climate resilience/risk assessment plans and strategies?
L	Learning and innovation	The public administration provides to society free-of-charge resources and materials to learn on expected climate change impacts and potential adaptation measures. Does your region actively participate in R&D projects?
I	Information and transparency: resilience as participation tool	Does your region have some national or sub-national online climate services portal, with information aggregate as climate indicators?
E	Environment (natural and built up)	Do you think that there are enough natural protected areas (NPAs) to buffer the potential impacts of climate change and conserve ecosystem services - e.g, water provisioning?
N	Networked systems and actors (multilevel governance)	Is there good coordination and collaboration between the different stakeholders (public authorities, water utilities, NGOs, SMEs, …) of your region for fostering climate resilience?

Acronym	Explanation	Specific question for the region
C	Capacity to transform after disturbance but maintain self-organisation	What is the "community-level recovery" from extreme weather events?
E	Equity and Justice: resilience measurements must not exclude others.	Are climate resilience/risk adaptation measures considering all people? - Leave no one behind approach

The "Explanation" column in Table 5 relates to conceptual framework that was introduced in section 3.2.1 by merging the concept of qualities (e.g. robustness) from Table 3, with the concept of dimensions (e.g. learning and innovation) and sectors (e.g. environment) from Figure 5.

Table 6 summarises the results obtained in Andalusian climate action assessment, which analysed the main impacts defined in Article 20 of Law 8/2018 in relation to the different strategic areas in terms of adaptation. different strategic areas in terms of adaptation, also defined in the Law. Rating of "27" in this table indicates the maximal risk, whereas the rating of "18" represents medium risk.

Within D1.2, such assessment was performed by all ClimEmpower regions, and a decision made to specifically address the risks deemed "medium" and "high" in ClimEmpower regions.

Table 6: Impacts classified as "high" and "medium" risk in the PAAC. Source: Plan Andaluz de Acción por el Clima [5]

IMPACT	a) Water resources.	b) Flood prevention.	c) Agriculture, livestock, aquaculture, fishing, and forestry.	d) Biodiversity and ecosystem services.	e) Urbanism and land use planning.	f) Health.	g) Tourism.	h) Energy.	i) Buildings and housing.	j) Mobility and infrastructure.	k) Commerce.	l) Coastal areas.	m) Climate-related migrations.	n) Insurance.
FLOODS (Pluvial, fluvial, storm surges, sea-level rise)	18	27	27		27	18	18			27		27		27
	27	27	18		27		27		18	27		27	27	27
c) Loss of biodiversity and alteration of natural heritage and ecosystem services.				18										
FOREST FIRES (F, D, I)		18	27	27	27		18							27
e) Loss of air quality.					18	18	18	18						
DROUGHTS (changes in water resources availability and quality)	27		27	27	18	27	27	18			18		27	
	27		27	27		27	27	18			27			
h) Processes of soil degradation, erosion, and desertification.		18	18	18										
i) Alteration of sediment balance in river basins.														
HEATWAVES (F, D, I)					27	27	27	27	27					
k) Changes in supply and demand in tourism.					18		18		18	18	18	18		
l) Seasonal modification of energy demand.							18	18						
m) Modifications in the electricity system: generation, transport, distribution, commercialization, and consumption, as well as potential inefficiencies or risks for rural areas.												18		
n) Increased risks to human health.						27	27						18	
o) Increased presence and intensity of pests and diseases in crops and livestock.			18	18		18								
p) Employment changes in affected strategic areas.			18										18	

[5] Plan Andaluz de Acción por el Clima https://www.juntadeandalucia.es/medioambiente/portal/landing-page-%C3%ADndice/-/asset_publisher/zX2ouZa4r1Rf/content/el-plan-andaluz-de-acci-c3-b3n-por-el-clima-2021-2030-/20151

4.2.6 Other sources

Relevant indicators from literature and one Austrian national project were also added, when deemed useful, to the indicators list. The used scientific papers are stated within the literature review document, whereas the VESPA project is introduced hereafter.

In a very recent project, named VESPA[6], a thorough study on indicators for vulnerability and resilience was conducted for developing a prototype for a rapid vulnerability assessment tool for cities. Since VESPA was coordinated by AIT, we possess in-depth insights into this project. Much of the expertise on key indicators provided in this task is based on this study. Accordingly, VESPA will be discussed in greater detail.

While diverse challenges and hazards affect cities and municipalities to very different degrees, individual impact and vulnerability is determined by fundamental economic, social, settlement, mobility, and landscape structures as well as local administration and governance. In VESPA, the extent of the negative impact of various challenges and hazards on a municipality is described using 28 vulnerability criteria in 7 thematic areas (settlement area & natural environment; economy & labour market; health, education & society; energy & water; traffic & IT infrastructure; population; governance).

A comprehensive catalogue of mostly quantitative indicators was created by the project team, capturing critical structural and institutional conditions within cities. This catalogue enables the identification, documentation, and mapping of various urban vulnerabilities, resulting in tailored vulnerability profiles for individual cities.

Through an iterative process with Austrian cities, the team has also refined the requirements for the web-based vulnerability-check tool, including considerations for data availability and data management at the municipal level. Based on this empirical groundwork, a digital tool was developed, implemented, and tested. Following a user-centred design approach, the tool was created in a participatory manner to ensure its practical relevance and applicability.

Resulting VESPA tool provides an evidence-based foundation to support political decision-makers and city administrations in their transformation towards more climate resilience. The research team collaborated closely with cities to address their specific questions about vulnerability, define key indicators for the web-based tool, and identify the necessary data inputs. The tool is divided into two components: the “Self-Check” and the “Full-Check.” The Self-Check (Figure 6) serves as a self-assessment designed to bring together relevant stakeholders and initiate discussions about vulnerabilities in the region. Following this, the Full-Check involves populating the indicators with statistical data and quantitative metrics.

[6] VESPA was funded by the Austrian Climate and Energy Funds Rapid vulnerability analysis for cities - AIT Austrian Institute Of Technology

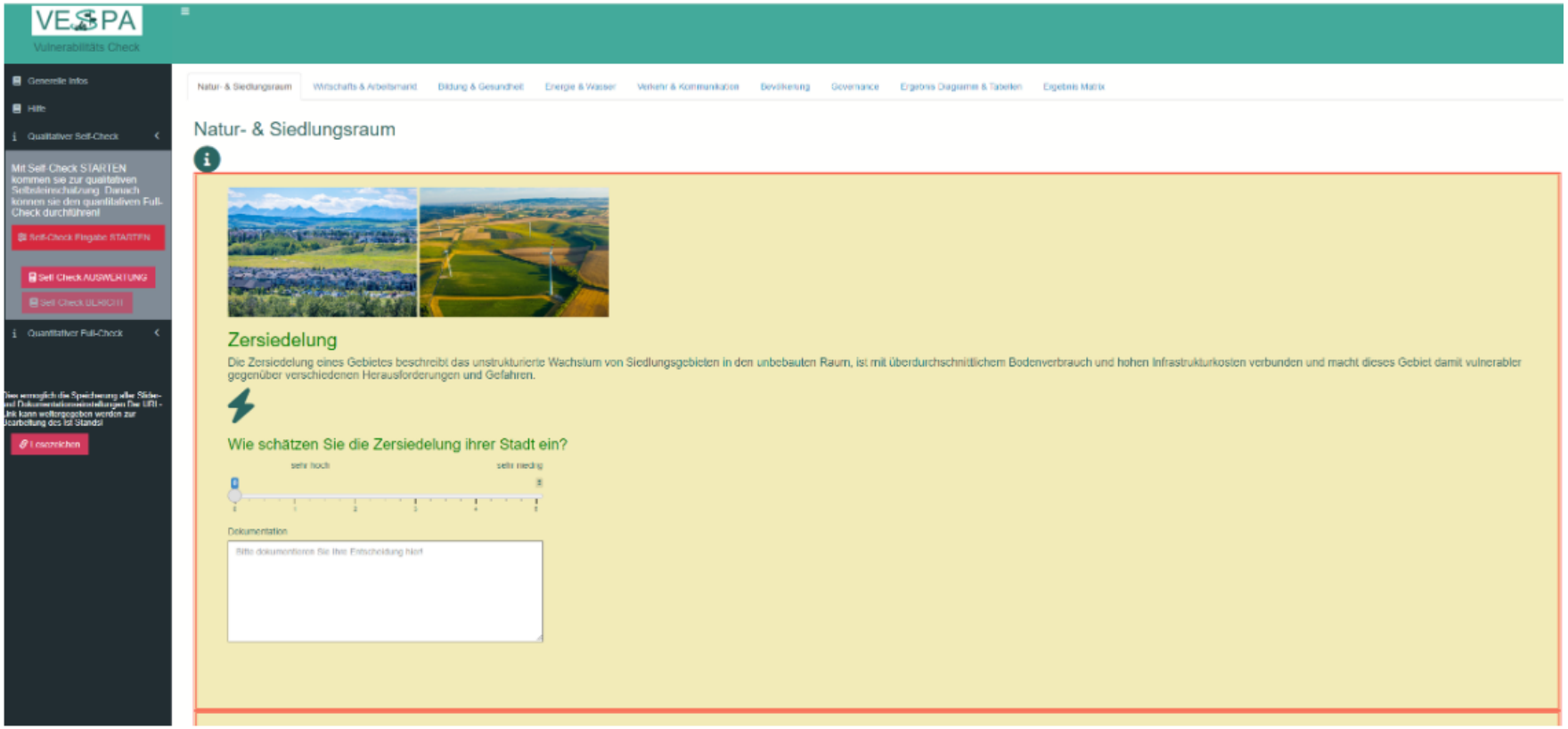

Figure 6: Example for VESPA "Self-Check" on "urban sprawl" [7]

[7] **Source:** https://cities.ait.ac.at/uilab/udb/home/dev/vespa/help/Userinterface.html

At the conclusion of the process, the results from the Self-Check and the data-driven Full-Check can be compared. This comparison highlights areas of alignment and discrepancy in the indicator values, fostering deeper insights and more informed decision-making.

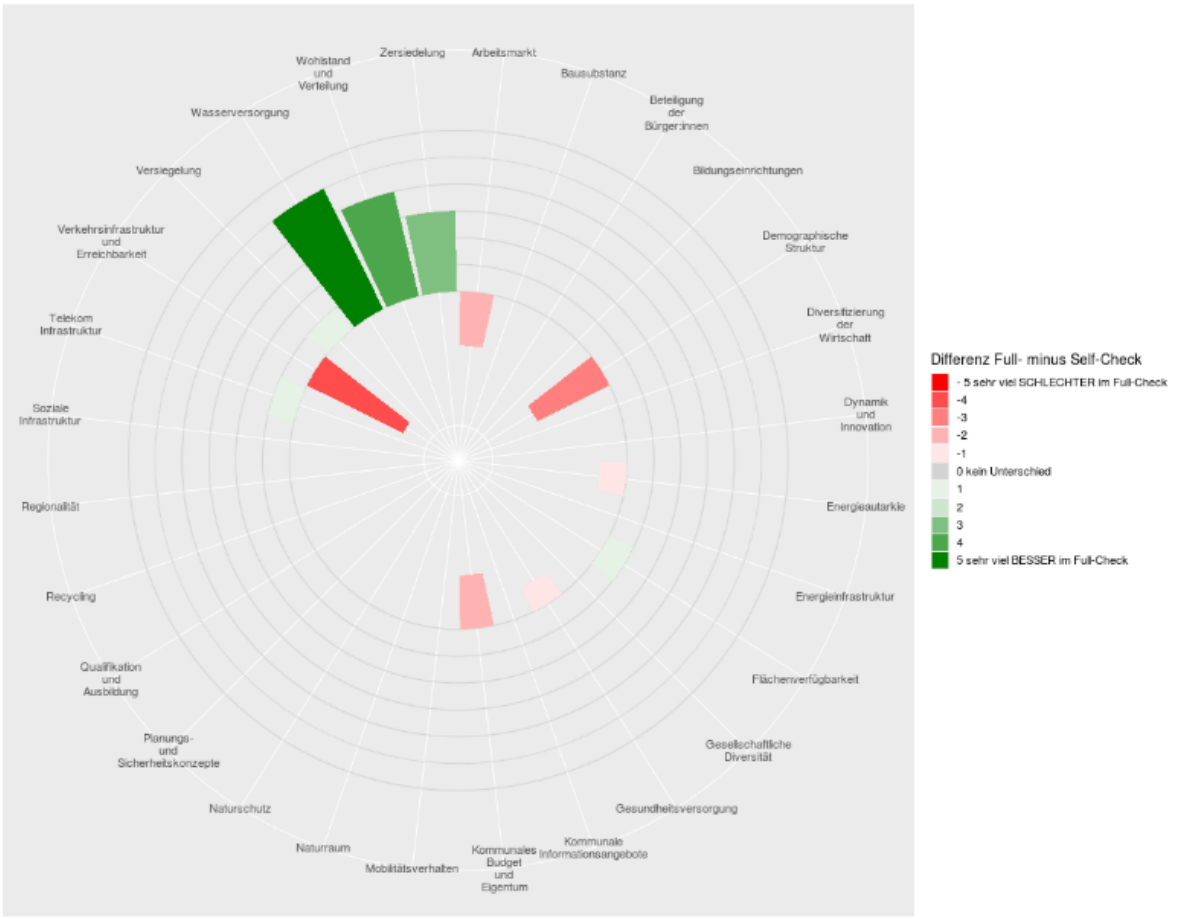

Figure 7: Visualisation of differences between VESPA Full-Check and the Self-Check[8]

4.3 Characterisation of indicators

The division of the analysed indicators into sectors follows the ISO 37123:2019 as stated above, with one additional "sector", Climate Change that incorporates all climate specific indicators.

Additionally, to follow the approach of IPCC/UNFCCC/Sendai DRR Framework, we analysed the indicators based on their emphasize:

- **Context-specific** – indicate if indicator links to hazard, exposure, vulnerability, impact, adaptation and if it is local/regional/national

[8] **Source:** https://cities.ait.ac.at/uilab/udb/home/dev/vespa/help/Full-Check.html

- **Measurable** – indicate if qualitative or quantitative, and in case of the latter how easy/difficult it is to retrieve the data needed for computation
- **Comparable** – quantitative indicators allow the comparison between regions
- **Actionable** – by monitoring the indicators, changes in resilience should be feasible to assess, under the assumption that the overall picture remains the same. Additionally, the easier the data needed to quantify the indicator is to retrieve, the more actionable it is assumed to be.
- **Aligned with local and national development goals** – this aspect will be discussed in more detail with the regional stakeholders of ClimEmpower.

Various sources were analysed, and the stated indicators put into the excel sheet, which has been subsequently published on Zenodo (Table 2). Their analysis was done according to the above-mentioned qualities (e.g. robustness) and to fulfil the stated requirements (e.g. measurable). It is important to keep in mind that this deliverable doesn't provide an extensive overview of all available indicators, as this goes beyond the resources and scope, but rather focuses on the most relevant organizations (UNFCCC, IPCC, ISO) and recent (e.g. RESILOC) definitions, as well as projects or definitions (Andalus, VESPA) from the consortium to provide an overall set of indicators that displays a starting point for WP2, WP3 and WP4.

5 Results

5.1 Resilience Framework

Based on the investigated sources, the decision was made to incorporate the ISO norm defined sectors but combine them to dimensions defined by the Arup framework.

Table 7: Assignment of ISO sectors to dimensions defined within the Arup resilience framework

Dimension	Included sectors
Health & Wellbeing	• Health • Population and social conditions • Agriculture & Food security
Economy & Society	• Economy • Finance • Education
Infrastructure & Environment	• Environmental • Transportation • Telecommunication • Solid Waste • Housing • Energy • Water
Leadership & Strategy	• Governance • Urban Planning • Safety

Furthermore, the resilience indicators defined in the project (section 5.5) are associated to dimensions/qualities from the Arup framework (section 3.2.1), thus establishing a clear link between the indicators and the adaptive capacity of the region, as one of the key elements of resilience.

5.2 Literature Review

5.2.1 Overview of the reviewed publications

With the contributions of project members from FRC, PLINIVS and AIT, **in total 44 publications** were reviewed (Figure 8).

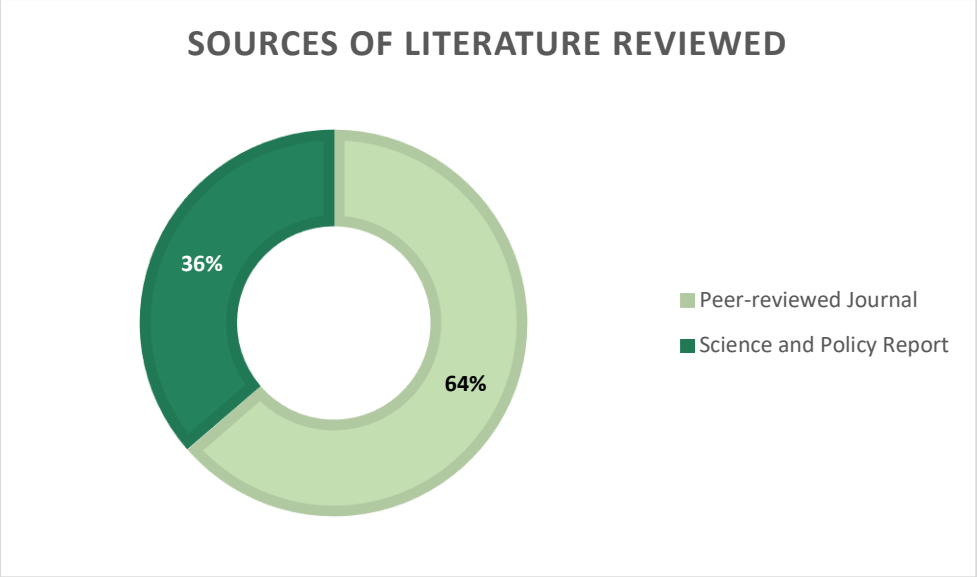

Figure 8: Overview of the publication sources for the literature review; own presentation.

Roughly 2/3rd of the analyzed reports were papers published in peer-reviewed scientific journals. Remaining reports consist of official reports from EU institutions, deliverables from relevant scientific projects, and reports issued by local administrative units.

The literature review focused on the assessment of regional, agricultural, and urban climate resilience. The distribution of these topics among the publications is shown in Figure 9. Since many papers focusing on regional indicators, address more specific indicator sets, like agriculture, the left panel of Figure 9 also depicts publications in the category 'regional, agriculture'.

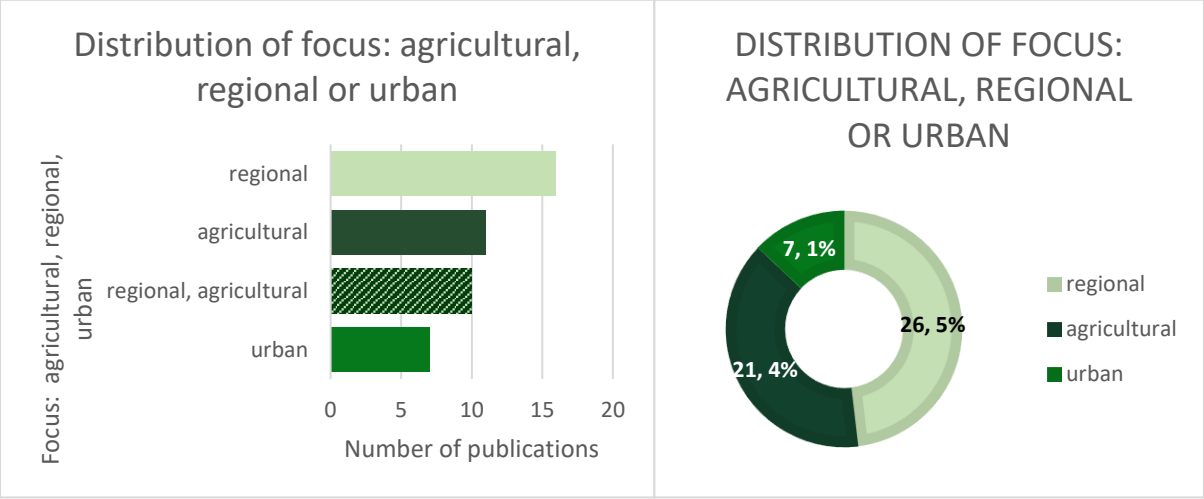

Figure 9: Focus (regional, agricultural, urban) of the reviewed publications; own representation.

Out of the 44 publications analysed by ClimEmpower team, 30 publications introduced concrete datasets, that were recommended or already applied to a certain region. Furthermore, climate related indicators, such as rainfall anomalies or temperature change,

were mentioned in 33 publications, while social or vulnerability related ones were discussed in 29, and the indicators with focus on governance in 24 publications (Figure 10).

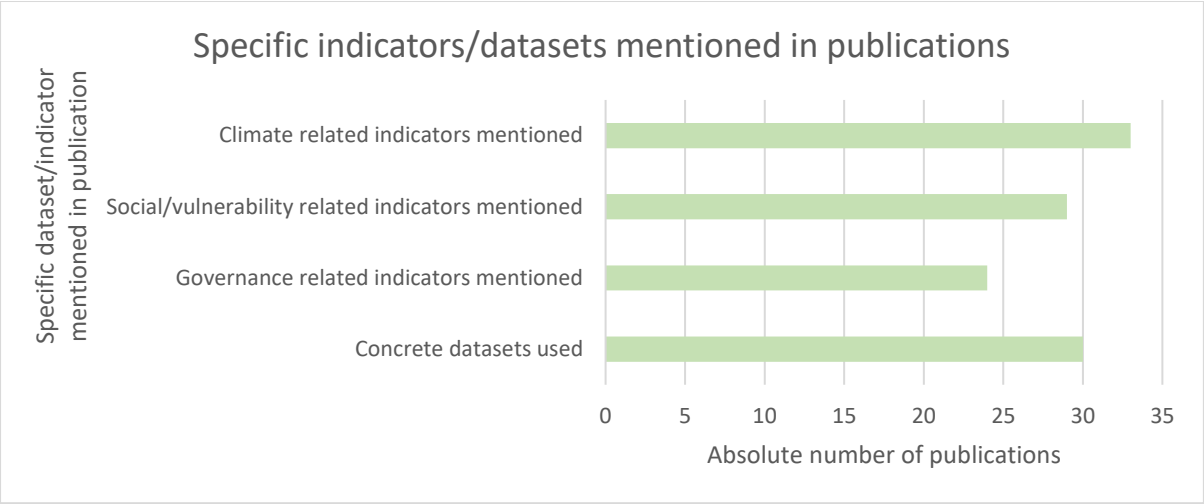

Figure 10: Specific indicators or datasets mentioned in the publications; own representation.

5.3 General take-aways and highlights

A broad overview of existing publications and highlights for further reading are given below for the assessment of regional (5.3.1), agricultural (5.3.1.1) and urban (5.3.2) climate resilience as well as a compilation of studies focusing on a ClimEmpower region (5.3.3). The relevancy of the literature review for the project will be explained in 5.3.4.

5.3.1 What indicators are recommended for what purpose at the regional scale?

A detailed list of current problems with resilient frameworks, for example administration is usually not considered enough, and a list of indicators linked to their justification for a region in Germany is given in Feldmeyer et al (2020). Something similar can be found in Douxchamps et al (2017), were a good overview of compound indicators currently available and their assessment is given.

Feldmeyer et al (2021) does rather focus on nations then regions but introduces a method to derive socio-economic and vulnerability information for an open resilience index from open data like OSM.

Regarding resilience to natural disasters, an assessment of multiple composite indices can be found in Bakkensen et al (2017). A validation for US counties is given as well, showing that most that most frameworks can reasonably well assess damage, some fatalities and only a few disaster declarations with significance.

Srinivasa Rao et al (2019) proposes a method on how to identify relevant indicators, in this case for agriculture resilience in India from a wide array and touches on the suitability and usefulness of individual indicators.

Singh et al (2021) does not focus on a ClimEmpower region but defines 26 major indicators relevant for climate resilience assessment of agriculture in India and combining them to a

composite index based weighted methodology containing socio-economic, technological, environment and infrastructure/governance factors.

5.3.1.1 Which recommended indicators specifically tailored to assess the climate resilience of agriculture exist?

Climate change poses significant challenges to agricultural systems, necessitating the development of indicators to assess its impacts and guide adaptation strategies. Several studies have proposed comprehensive frameworks for evaluating climate-resilient agriculture (CRA). These include climate indicators like temperature and precipitation, as well as crop and livestock indicators such as animal heat stress (Walsh et al., 2020, Srinivasa Rao et al (2019)). Biological, phenological, and socioeconomic indicators are also considered crucial for understanding climate change effects on agriculture (Walsh et al., 2020; Hatfield et al., 2018). Some key indicators with historical records, such as crop progress and productivity, can provide valuable insights into long-term climate impacts (Hatfield et al., 2018). A more recent framework proposes 71 evaluation indicators across four dimensions: agricultural productivity, farmer income, climate adaptability, and green development level (Zong et al., 2022) and is shown in Figure 11.

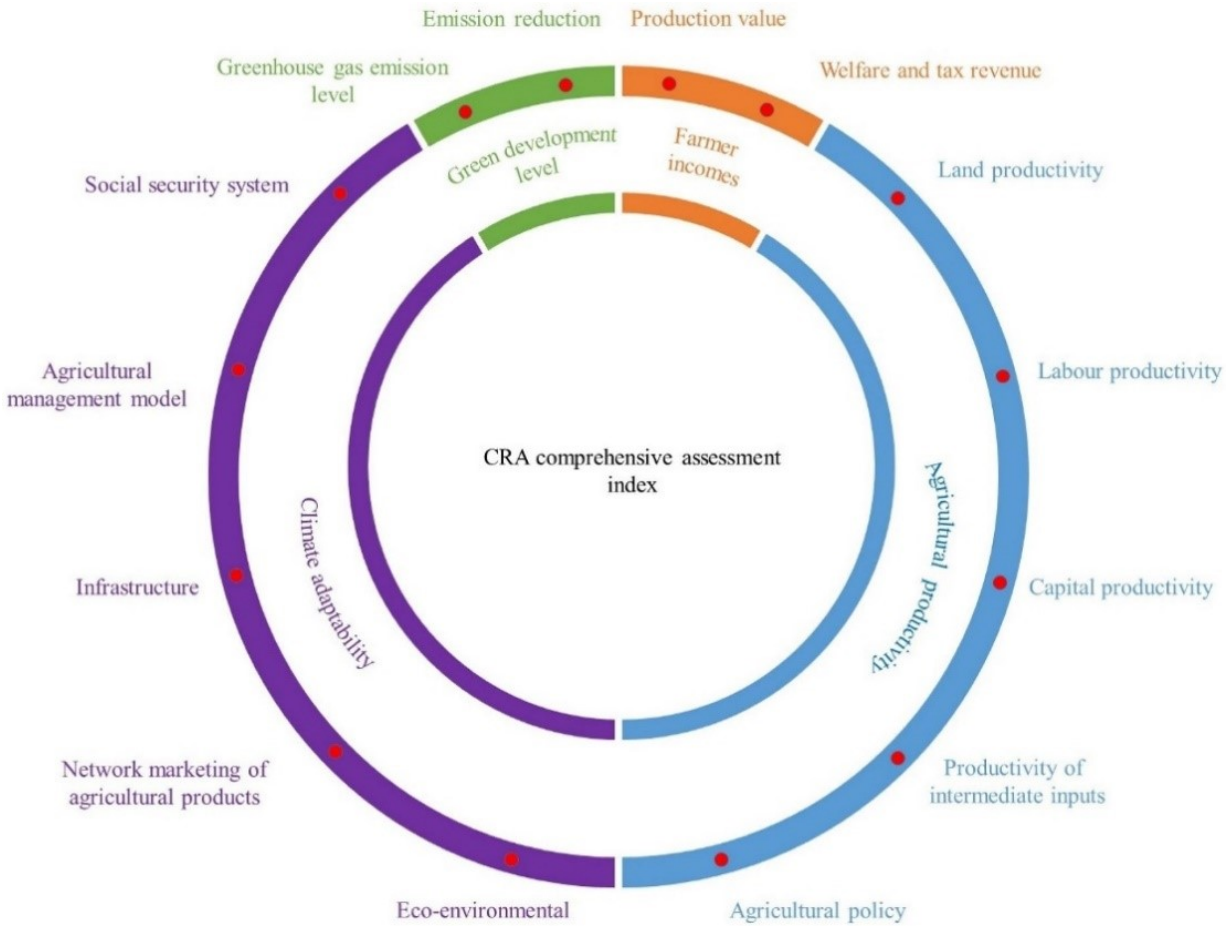

Figure 11 Indicator sectors recommend for the assessment of CRA. Source: Zong et al (2022)

5.3.2 What indicators are recommended for what purpose at the urban scale?

Several studies have been conducted on relevant indicators at the urban scale. The UNDRR Disaster Resilience Scorecard for Cities (UNDRR, 2017) identifies key indicators for distinct

purposes, such as assessing risk, planning interventions, and improving resilience. These indicators are targeted at local governments to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 and to evaluate urban resilience.

Additionally, Barzaman et al. (2022) investigates urban climate resilience in Varamin, Iran, using the Analytic Network Process (ANP) to evaluate resilience across four components: environmental, socio-economic, infrastructural, and institutional. The study identifies 33 resilience indicators, with a particular focus on water resource depletion, land use change, informal settlement density, and air quality.

However, while these frameworks can provide valuable guidance, resilience indicators must be tailored to conditions and needs of each city, as they may face different stages of preparedness to address urban challenges (Tyler et al, 2016). Thus, the replication and development of indicators require collaboration with local stakeholders and the consideration of data gaps and availability in each city (Singh et al., 2013; Zhang et al.,2020; Tyler et al, 2016).

5.3.3 Which projects and studies have already utilised climate resilience indicators in ClimEmpower regions?

Regarding Italy, Marzi et al (2019) assesses the climate resilience on the municipality level and gives a detailed description of the used datasets. Another example from Italy is Alfieri (2024), where the focus lays also on identifying indicators for climate smart forestry, which is resilient towards droughts and fires.

Politi (2024) describes the application of the EFFIS fire risk framework (EFFIS fire risk indicators from drought) for a region in Greece that is close to the ClimEmpower PSTE region. However, this study neglects socioeconomic/governance factors.

Payab (2023) applies the CROPWAT simulation tool from FAO and various drought indicators for agricultural resilience to Northern Cyprus.

Several studies exist for the region of Andalusia. However, none focuses solely on Costa del Sol. Gratsea (2022) for example studies agroclimatic indices for olive trees in Andalusia and features a subsequent assessment.

In Andalusia, a methodological guide exists with recommended indicators to evaluate different components of risk at various strategic areas (Oficina Andaluza de Cambio Climático, 2023), one of them at the urban scale. These indicators address hazard (e.g., pluvial and coastal flooding, forest fires or heat waves), exposure (e.g., the ratio of newly constructed areas, buildings exposed, land use indices, etc.), sensitivity (e.g., access to insurance services, infrastructure characteristics, population, among others), and adaptive capacity (e.g., investments, green areas...).

While no studies have been found in Sicily, Marrone P (2018), which focuses on the Italian city of Rome, may be a good starting point for Sicily. This study evaluates adaptation and mitigation measures in open public spaces, and it addresses the urban heat island effect and hydrological risks, identifying indicators related to surface temperature, soil permeability, and stormwater management.

No additional studies at urban level evaluating indicators in the ClimEmpower case studies have been discovered/analysed.

5.3.4 Relation of results to ClimEmpower

Existing, globally defined, composite indices that were analysed by ClimEmpower team do not capture the multidimensional aspects of climate resilient development. Many of the climate risk indices from the analysed literature aren't directly usable for ClimEmpower regions. Their theoretical frameworks are often only vaguely (or not at all) defined and the indicators often focus on current climate risk as opposed to future hazards. Moreover, the economic and ecological aspects are often neglected or ill-defined and therefore difficult to handle in practice (Miola, 2015). The literature research shows that a globally defined composite index not specifically designed for the region, can be a first guess on the region's resilience, but for a more profound assessment, a list of applicable indicators is recommended (Bakkensen, 2017), (Summers, 2017). Therefore, detailed recommendations and lists vary – however a representation of the environment, society (socio-economic), governance and administration and risk indicators is commonly agreed on. For special purposes, for example the resilience assessment of viticulture, finance is often also handled as an individual field of indicators (Tscholl, 2024).

None of the screened studies provides an indicator list specific to a ClimEmpower region. However, lists for larger areas containing a region or lists for places close to the regions do exist. The regional assessments often focus on one specific area of interest, typically related to agriculture. Socio-economic or governance factors are mostly neglected (Marzi, 2019, Alfieri, 2024, Payab, 2023, Politi, 2024, Gratsea, 2022, Mysiak, 2018), although they are recommended as well for the assessment of CRA (Walsh et al., 2020; Hatfield et al., 2018, Zong et al 2022).

The presented guides, such as the Andalusian Methodological Guide (2023) and the UNDRR Disaster Resilience Scorecard for Cities (2017), provide a solid starting point for identifying relevant indicators to assess resilience at the urban scale. These resources can assess with the creation of tailored indices that capture the multidimensional aspects of urban resilience, ensuring alignment with the challenges identified in ClimEmpower regions.

Research on indicators such as those evaluated by Marrone (2018) and De Moel et al. (2015) is also relevant to ClimEmpower as they target common urban hazards identified across most of the project regions. Specifically, De Moel et al. (2015) compares flood risk assessment methodologies across various scales, offering insights into indicators that are critical for urban flood resilience. Similarly, Marrone (2018) examines urban heat island effects and hydrological risks, identifying indicators that address these challenges.

5.4 Indicators Collection

As mentioned above, the collected indicators aren't complete, as this goes beyond the scope of this deliverable, but represent the state-of-the-art documents and approaches. To enable the inclusion of relevant indicators for the ClimEmpower regions, the document will be treated as living document until the projects end. Furthermore, we focus on single, rather than composite indices, to facilitate the interpretation by the regional authorities.

For each indicator the following information was entered, based on the findings from Chapter 3:

- If it belongs to a composite indicator (consisting of multiple indicators): composite index name.

- Name of indicator.
- Short description.
- Source.
- Related category (hazard, exposure, vulnerability, impact, adaptation).
- Qualitative or quantitative?
- Expected data source (e.g. open data, insurance data,…).
- Spatial granularity (e.g. national, regional,…).
- (assumed) data availability (easy, medium, difficult).
- Change relates to changed resilience (1=change in indicator doesn't necessarily relate to altered resilience, 3=change in indicator directly allows assumption about resilience).

The last information is important for T2.3, where recommendations regarding the collection of data to quantify indicators, are given.

Overall, 531 indicators were analysed within 16 sectors as defined by ISO 37123:2019, plus the "sector" Climate Change, that relates to indicators focusing on climate hazards (e.g. maximum rainfall intensities over 1 day). The sector "Environmental" includes most indicators, almost 24%, with about 130 (Figure 12, Figure 13), that relate mainly to vulnerability and exposure (Figure 13).The second prominent sector is "Governance", with roughly 14% and about 80 indicators, that are divided within all categories. The 3rd prominent sector is "Economy" with 9% and about 50 indicators, mainly related to vulnerability (Figure 13).

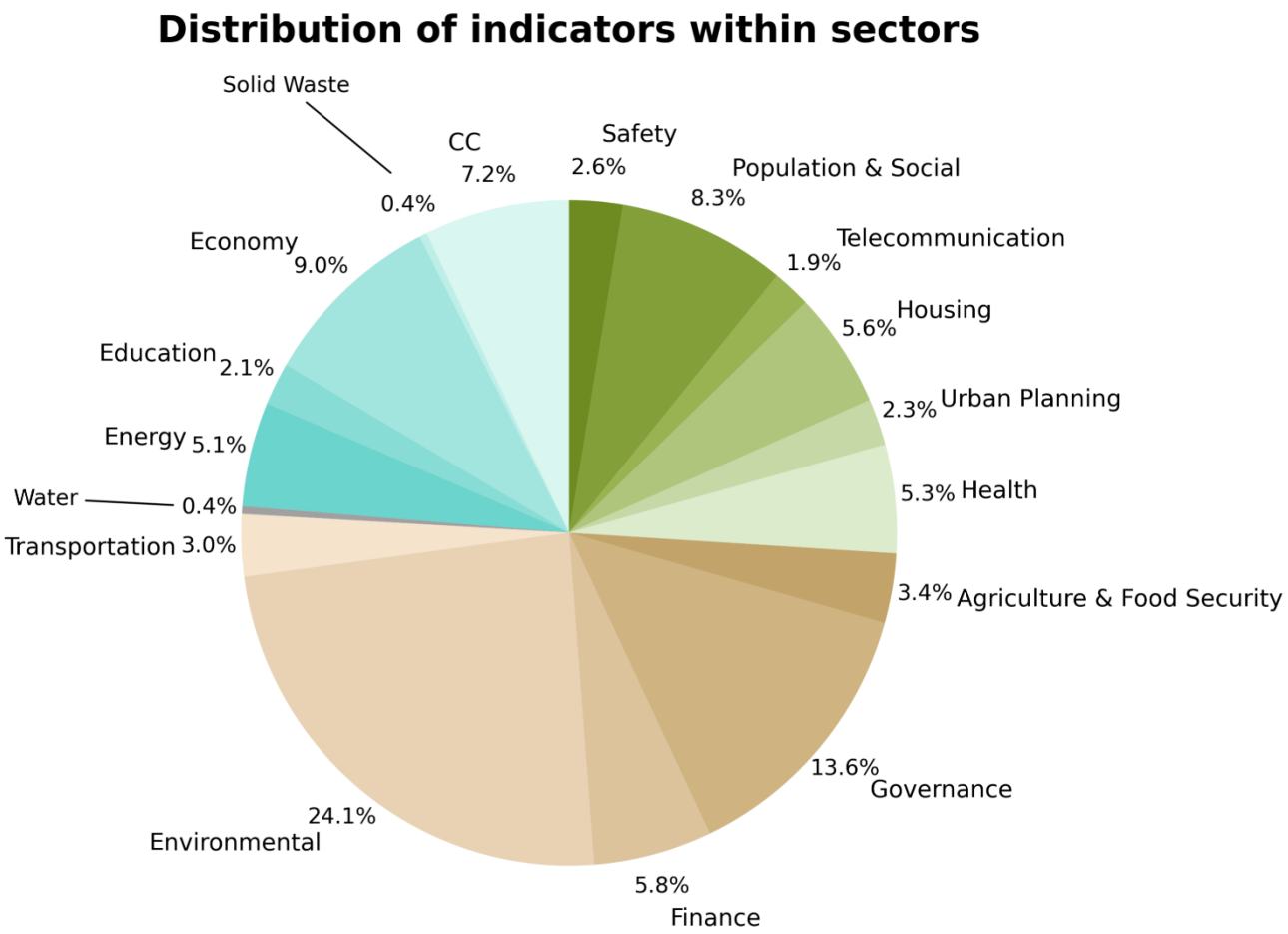

Figure 12: Percentage distribution of resilience indicators within different sectors.

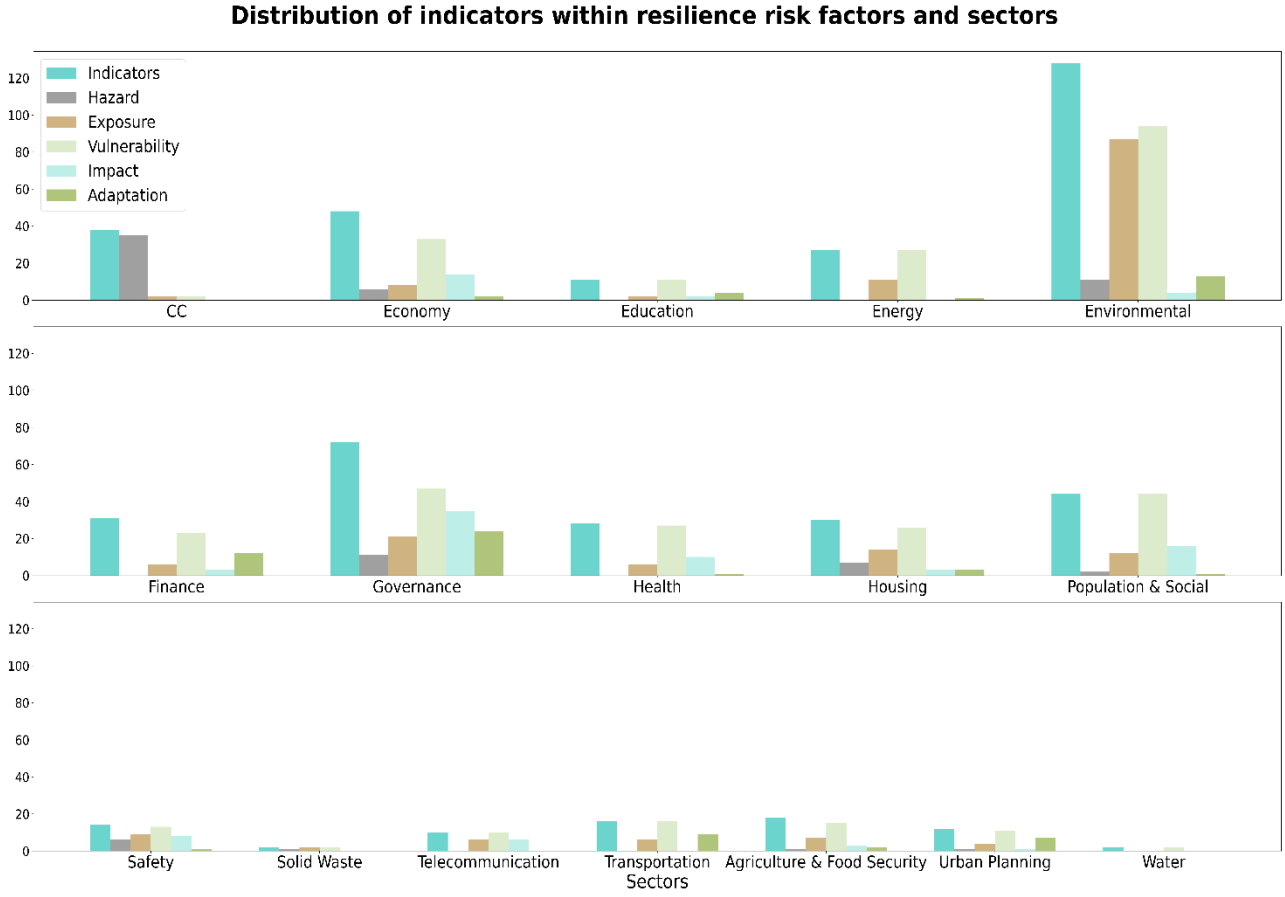

Figure 13: Distribution of resilience indicators within different risk factors (hazard, exposure, vulnerability, impact, adaptation) for the different sectors.

Investigating the distribution of indicators per sector according to the applied category, displays a clear prominence of vulnerability indicators, which displays the strong link between resilience and vulnerability, as well as the possibilities to increase resilience trough decreased vulnerability.

As depicted within Chapter 3, the robustness of indicators, their monitoring and comparability are of great importance to ensure their applicability and sustainability. Therefore, the focus was on quantitative indicators. Furthermore, climate services, as envisioned within WP3, rely on quantitative indicators to empower regions in their strategies for improved climate resilience.

5.5 Specific Indicators

Even though the indicators collected don't represent all available ones, the list is too extensive to be used and filled in by regions. Additionally, not all indicators display the same potential and relevance, as also investigated within the VESPA project (see 4.2.6). Therefore, as a first step, three indicators were selected for each of the relevant sectors and depicted in more detail hereafter. The selection was done regarding the source, anticipated applicability to the regions, and previous expertise. It is meant to give a first understanding of the sectors and possible indicators. Selection of concrete indicators to use in each of the ClimEmpower regions will be done in WP4, in collaboration with the CoPs.

The indicators are organised in four dimensions following the Arup framework, and further subdivided into sixteen ISO 37123:2019 sectors, as defined in section 5.1. Furthermore, the indicators are associated to dimensions/qualities from the Arup framework (section 3.2.1) and possible datasets for estimating the indicator value indicated where possible.

5.5.1 Health & Wellbeing

5.5.1.1 Health

Table 8: Example of most relevant indicators for the sector "Health"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Number of hospital beds per 1000 inhabitants in the community (quantitative)	The number of hospital beds available per 1000 inhabitants, indicating healthcare system capacity to manage health crises and provide medical care in emergencies. Source: RESILOC_D3.1 Relates to: vulnerability Data sources: health authorities, hospitals Spatial granularity: governance region Data availability: medium Change of this indicator related to changed resilience: high	Robustness, Redundancy, Integration	health care statistics - EUROSTAT Greece: demographic information - Hellenic Statistical Authority
% of people with immediate access to first aid (quantitative)	The percentage of the population who can access first aid services or equipment within a short time, especially during emergencies or accidents Source: RESILOC_D3.1 Relates to: vulnerability Data sources: regional authorities, OSM data Spatial granularity: governance region Data availability: easy to medium Change of this indicator related to changed resilience: high	Robustness, Redundancy	OSM data on critical infrastructure EUROSTAT – health care statistics
Heat-related morbidity and mortality (quantitative)	Number of increased health problems and deaths after a heatwave Source: IPCC Global to Regional Atlas Relates to: impact Data sources: health authorities, hospitals Spatial granularity: governance region Data availability: easy to medium Change of this indicator related to changed resilience: high	Robustness, Reflectiveness	

5.5.1.2 Population and social conditions

Table 9: Example of most relevant indicators for the sector "Population and Social conditions"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Population density (quantitative)	Number of inhabitants per unit area (e.g. km²) Source: scientific publication (Singh 2021) Relates to: exposure, vulnerability Data sources: national statistics, open-source data Spatial granularity: unit area Data availability: easy Change of this indicator related to changed resilience: low	• Resourcefulness, • Redundancy	population statistics (population numbers) - EUROSTAT population projections - EUROSTAT (Greece: population numbers Italy: Population, census sections Andalusia: population numbers Croatia: National statistics Spain: Population age, sex)
Percentage of single parent families (quantitative)	The percentage of single parent families over total number of families Source: scientific publication (Marzi 2021) Relates to: vulnerability Data sources: regional authorities, national statistics Spatial granularity: governance region Data availability: medium Change of this indicator related to changed resilience: low	• Robustness	population statistics (population numbers) - EUROSTAT population projections - EUROSTAT
Annual percentage of the city population directly affected by natural hazards (quantitative)	The number of people directly affected (i.e. evacuated, relocated, injured or sickened) by natural hazards is a measure of a city's vulnerability. In some cases, it is a more relevant measure of disaster impact than the number of deaths. Source: ISO: 37123:2019 Relates to: vulnerability Data sources: emergency management authorities, open source climate data and statistics	• Robustness, • Reflectiveness	Climate data store: flood risk indicators - COPERNICUS climate data store EUROSTAT population indicators

	Spatial granularity: governance region Data availability: medium Change of this indicator related to changed resilience: high		

5.5.1.3 Agriculture and food security

Table 10: Example of most relevant indicators for the sector "Agriculture and food security"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Percentage of city population served by city food reserves for 72 hours in an emergency (quantitative)	Mechanisms can be put in place to ensure continuity of essential food supplies during an emergency or due to shocks, when city supply chains are disrupted or stopped. Source: ISO37123:2019 Relates to: vulnerability Data sources: Emergency management department of the city/region. Spatial granularity: administrative district Data availability: medium to difficult Change of this indicator related to changed resilience: low	• Reflectiveness, • Robustness, • Resourcefulness, • Inclusivity	
Percentage of arable land that is cultivated (quantitative)	Measures the proportion of total arable land area that is actively used for agricultural production. Source: RESILOC_D3.1 Relates to: exposure, vulnerability Data sources: satellite images, local authorities Spatial granularity: administrative district Data availability: easy Change of this indicator related to changed resilience: high	• Robustness, • Flexibility	Socio-economic data for crop yield - Food and Agriculture Organization of the United Nations Agro-climatic resources - Food and Agriculture Organization of the United Nations EUROSTAT – agri environmental indicators
Percentage of city population living within one kilometre of a grocery store	Proximity to good quality and affordable food is a challenge for many city residents. Nearby grocery stores can provide access to good quality and affordable food,	• Reflectiveness, • Robustness, • Resourcefulness, • Inclusivity	OSM data

	which improves the health, productivity and general prosperity of city residents, as well as the overall resilience of a city. Source: ISO 37123:2019 Relates to: vulnerability Data sources: OSM Data availability: easy Change of this indicator related to changed resilience: high		

5.5.2 Economy & Society

5.5.2.1 Economy

Table 11: Example of most relevant indicators for the sector "Economy"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Historical disaster losses as a percentage of city / regional product (quantitative)	Monetary loss due to natural disasters over the past 5 years / city product (5 yrs)]*100. Source: ISO37123:2019 Relates to: vulnerability Data sources: City authorities and insurances. Spatial granularity: administrative district Data availability: medium to difficult Change of this indicator related to changed resilience: high	• Reflectiveness, • Robustness, • Resourcefulness, • Inclusivity	EM-DAT disaster database - The Centre for Research on the Epidemiology of Disasters (CRED)
Unemployment rate - % of active population (quantitative)	The percentage of the labor force (active population) that is not employed but actively seeking work. Source: scientific paper, RESILOC_D3.1 Relates to: vulnerability Data sources: Eurostat, national, regional data Spatial granularity: administrative district Data availability: easy Change of this indicator related to changed resilience: medium	• Robustness, • Redundancy	population statistics - EUROSTAT
Percentage of total insured value to total value at risk within the city/region (quantitative)	An aggregate assessment of insurance levels relative to the value at risk from high-risk hazards helps to reveal potential instances of underinsurance	• Reflectiveness	

	Source: ISO 37123:2019 Relates to: vulnerability Data sources: insurances, administration sources Spatial granularity: administrative district Data availability: medium to difficult Change of this indicator related to changed resilience: high		

5.5.2.2 Finance

Table 12: Example of most relevant indicators for the sector "Finance"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Annual expenditure on emergency management planning as a percentage of total city/regional budget	Budgeting for emergency management planning helps cities to create a detailed plan of action so that the city can adequately respond to shocks and stresses. Source: ISO 37123:2019 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high	• Reflectiveness, • Resourcefulness, • Robustness, • Redundancy, • Flexibility, • Inclusiveness, • Integration	
Government spending on environmental maintenance for resilience	Measures the per capita spending by local/regional governments on environmental maintenance and regeneration projects with co-benefits for disaster resilience. Source: ISO 37123:2019 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high	• Robustness, • Reflectiveness	
Annual expenditure on upgrades and	Upgrading and maintenance of city/regional services helps	• Robustness	

maintenance of city service assets as a percentage of total city/regional budget	to ensure a more resilient city. If the assets to provide these services are not maintained and/or upgraded, the level of service over time is likely to decline and to be more vulnerable to disruption during shocks and stresses Source: ISO 37123:2019 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high		

5.5.2.3 Education

Table 13: Example of most relevant indicators for the sector "Education"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Literacy index	percentage of population with the ability to read and write Source: scientific paper (Singh 2021) Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: medium Change of this indicator related to changed resilience: medium	• Resourcefulness, • Flexibility, • Inclusivity	Education and training statistics at regional level - EUROSTAT
Percentage of population trained in emergency preparedness and disaster risk reduction	Training in emergency preparedness and disaster risk reduction enhances the response capacity of city populations. Source: ISO: 37123, RESILOC_D3.1 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high	• Robustness, • Flexibility, • Inclusivity	

% of households having received education or acquired skills relating to recovery procedures from disasters	Measures the percentage of households that have received education or acquired skills about recovery procedures after a disaster. Source: RESILOC_D3.1 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high	• Robustness, • Flexibility, • Inclusivity	

5.5.3 Infrastructure & Environment

5.5.3.1 Environmental

Table 14: Example of most relevant indicators for the sector "Environmental"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
% of Population in Areas at Risk from Landslides	Measures the proportion of the total population residing in regions identified as being at risk of XX. Source: RESILOC_D3.7 (generalized) Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: easy Change of this indicator related to changed resilience: high	• Reflectiveness	CDS & EUROSTAT
Percentage of area of green infrastructure in the community	Measures the proportion of land in a community dedicated to green infrastructure, which enhances ecological resilience. Source: RESILOC_D3.7 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: easy Change of this indicator related to changed resilience: high	• Robustness	CDS, CLMS, Regional land use data

Annual soil sealing index	Measures the soil sealing changes per year in km^2 Source: Andalusian methodology Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: easy to medium Change of this indicator related to changed resilience: medium - high	• Reflectiveness	Satellite land use data Bio-geophysical Parameters - COPERNICUS land monitoring service Agro-ecological zones and water resources - Food and Agriculture Organization of the United Nations

5.5.3.2 Transportation

Table 15: Example of most relevant indicators for the sector "Transportation"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
% of people with access to alternative transport routes	The percentage of the population who have access to alternative transport routes (e.g., detours, secondary roads) during disruptions to primary transport infrastructure (e.g., road closures, accidents, extreme weather). Source: RESILOC_D3.1 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: medium	• Flexibility, • Redundancy	
% of people who have access to public transport	The percentage of individuals or households in the community that own a personal vehicle (e.g., car, motorcycle, bicycle). This can influence mobility, independence, and resilience during emergencies. Source: RESILOC_D3.1 Relates to: vulnerability Data sources:	• Flexibility	

	Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: medium		
Number of evacuation routes available per 100,000 population	Accessible, well-documented and publicised evacuation routes and exit strategies are necessary to ensure mass movement of people safely and quickly away from a disaster. Source: ISO 37123 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high	• Flexibility, • Redundancy	

5.5.3.3 Telecommunication

Table 16: Example of most relevant indicators for the sector "Telecommunication"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Percentage of emergency responders in the city equipped with specialized communication technologies able to operate reliably during a disaster event	Mobile telecommunications networks (e.g. terrestrial cell antennae) can be damaged or overly congested during a disaster event. Having a privileged-access subscriber identity module (SIM) installed in handsets can help emergency responders to avoid such problems and safely connect to their networks during and after a disaster event. Source: ISO37123 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high	• Robustness	

5.5.3.4 Solid Waste

Table 17: Example of most relevant indicators for the sector "Solid Waste"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Number of active and temporary waste management sites available for debris and rubble per square kilometre	Debris removal and processing can be critical to helping a city/region recover from a disaster. It is essential to dispose of debris that is blocking rescue and emergency response activities. Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: medium	• Redundancy	EUROSTAT

5.5.3.5 Housing

Table 18: Example of most relevant indicators for the sector "Housing"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Percentage of buildings structurally vulnerable to high-risk hazards	The vulnerability of a city's /region's building stock to severe damage or collapse during a disaster is vital to overall resilience. Assessment and review of building vulnerability can help cities/regions to identify structures in need of repair, retrofit or rebuilding. Source: ISO 37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high	• Robustness	
Percentage of residential properties located in high-risk zones	Properties located in high-risk zones are especially vulnerable to damage or destruction during disaster events. Controlling the type	• Reflectiveness	OSM, CDS • Cyprus: population/housing data - CYSTAT

	and location of property development is a key strategy for cities to avoid and reduce risks from natural hazards. Source: ISO 37123, VESPA Relates to: vulnerability Data sources: easy Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high		• Sicily: Regional Technical Cartography - Regional Technical Cartography
Capacity of designated emergency shelters per 100,000 population	Emergency shelters are places of rest, reprieve and recuperation for people displaced by shocks and stresses. They are essential to a city's capacity for disaster preparedness and response, and therefore resilience. Source: ISO 37123 Relates to: vulnerability Data sources: difficult Spatial granularity: administrative district, national Data availability: Change of this indicator related to changed resilience: high	• Integration	

5.5.3.6 Energy

Table 19: Example of most relevant indicators for the sector "Energy"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
% of houses (public, private, businesses) connected to the electricity grid	The percentage of residential households connected to the national or regional electricity grid, providing access to electricity for lighting, heating, and other energy needs. Source: RESILOC_D3.1 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: easy Change of this indicator related to changed resilience: medium	• Integration	European data

Percentage of critical facilities served by off-grid energy services	Power outages of any duration are especially problematic for critical facilities, such as hospitals, fire stations, police stations, emergency services call centres, wastewater treatment plants or storage facilities for critical records. Source: ISO 37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: medium Change of this indicator related to changed resilience: high	• Redundancy, • Flexibility, • Resourcefulness	
Share of renewables of total energy demand	A diverse electricity supply mix helps ensure that alternative electricity provisions are available to the city in the event of a system failure, resulting in no or reduced power delivery or supply capacity. Source: ISO 37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: medium Change of this indicator related to changed resilience: medium	• Redundancy, • Flexibility, • Resourcefulness	EEA
Electricity Critical Asset (ECA) Loss Factor	A calculated factor that combines the recovery time (days) and the extent of critical assets affected by a disruption in the electricity grid. If: a = estimated # of days to restore regular service area-wide and b = % of critical assets affected… then ECA loss factor = a x b Source: RESILOC_D3.1 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: difficult	• Robustness	

	Change of this indicator related to changed resilience: high		

5.5.3.7 Water

Table 20: Example of most relevant indicators for the sector "Water"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Number of different sources providing at least 5% of total water supply capacity	A diversity of water sources and distribution systems ensures that alternative water supplies are available during system failure or disruption from the effects of disasters and shocks. The main goal is the provision of safe drinking water that will safeguard the health of inhabitants. Source: ISO 37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high	• Robustness, • Redundancy, • Flexibility	
Percentage of city population that can be supplied with drinking water by alternative methods for 72 hours	Providing drinking water is critically important to the response efforts for a disaster event. It is important that city water providers and local governments ensure effective planning for alternative (i.e. backup) drinking water supply methods during and immediately after a disaster event or system disruption. Source: ISO 37123 Relates to: vulnerability Data sources:	• Robustness	

	Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high		

5.5.4 Leadership & Strategy

5.5.4.1 Governance

Table 21: Example of most relevant indicators for the sector "Governance"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Availability of hazard maps	Availability of hazard maps that help identify and understand local risks and hazards Source: RESILOC_D3.1 Relates to: hazard Data sources: Spatial granularity: administrative district Data availability: easy Change of this indicator related to changed resilience: medium	• Inclusivity, • Reflectiveness	CDS
Percentage of public meetings dedicated to resilience in the city	Public meetings in cities help to promote and enable inclusive and collaborative approaches to resilience planning, enhancing citizen engagement and citizen-driven strategies in creating a more resilient city/region Source: ISO 37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district Data availability: difficult Change of this indicator related to changed resilience: high	• Integration, • Reflectiveness, • Flexibility, • Inclusivity	
% who have taken steps to prepare for a disaster affecting their home	The percentage of the population who have taken practical steps to prepare their homes for a potential disaster (e.g., securing heavy objects, emergency kits) Source: RESILOC_D3.1 Relates to: vulnerability Data sources:	• Reflectiveness	

	Spatial granularity: administrative district Data availability: difficult Change of this indicator related to changed resilience: high		

5.5.4.2 Urban Planning

Table 22: Example of most relevant indicators for the sector "Urban Planning"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
Percentage of city land area in high-risk zones where risk-reduction measures have been implemented	Property and people located in high-risk zones are vulnerable to the damaging, destructive and deadly effects of disasters. Source: ISO:37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district Data availability: medium to difficult Change of this indicator related to changed resilience: high	• Robustness	
Annual number of critical infrastructures affect by extreme event (e.g. flooding) as a percentage of critical infrastructure in the city/region	With the increasing frequency of severe weather events, it is essential that critical infrastructure is protected from flooding. Cities/Regions also play a critical role in mitigating flooding, for example through planning controls and construction and maintenance of storm water infrastructure. Source: ISO:37123 Relates to: vulnerability Data sources: Spatial granularity: administrative district Data availability: easy Change of this indicator related to changed resilience: high	• Robustness	CDS & OSM

5.5.4.3 Safety

Table 23: Example of most relevant indicators for the sector "Safety"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets

% of people in the community reached by EWS	The proportion of the population that receives alerts and notifications from early warning systems to prepare for impending hazards or disasters. Source:RESILOC_D3.1, ISO:37123 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: difficult Change of this indicator related to changed resilience: high	• Inclusivity, • Integration	
Percentage of emergency responders who have received disaster response training	Emergency responders are among the first people to arrive at the scene of an emergency related to a disaster event. Response training is therefore a critical element of disaster preparedness. Source: ISO:37123 Relates to: vulnerability, adaptation Data sources: Spatial granularity: administrative district, national Data availability: diffcult Change of this indicator related to changed resilience: high	• Inclusivity, • Integration	

5.5.5 Climate Change Indicators

Table 24: Example of most relevant indicators for the sector "Climate Change"

Name of indicator	Description	Related qualities (Arup)	Possible Datasets
annual frequency of extreme heatwave events	Extreme heat events shall refer to an extended period of time (at least 72 hours) with unusually hot weather conditions that put human health and well-being at risk	• Robustness, • Reflectiveness	CDS
annual frequency of extreme rainfall events	Extreme rainfall events shall refer to precipitation events in which 50 mm or more of rain has fallen	• Robustness, • Reflectiveness	CDS

	within the city over a 24-h period		ClimINVEST: indicators - ClimINVEST • Greece: Extreme rainfall risk zones - Ministry of Climate Greece • Andalusia: Rainfall deficit - Region of Andalusia • Sicily: rainfall anomaly prognosis - Region of Sicily
12-month SPI, we use only the severe (S) and extreme severe (E) drought events as in SPI-3	a drought measure specified as a PR deficit on 12-month scale	• Robustness, • Reflectiveness	CDS
Frequency of floods per unit area / year	based on hist. Floods	• Robustness, • Reflectiveness	CDS

6 Conclusions

ClimEmpower Resilience Framework

The development of resilience frameworks and related indicators has undergone constant (slight) changes and is not a static definition, representing the changes in conditions and backgrounds. Moreover, there is no general valid definition what sectors (e.g. transport, agriculture), dimensions (e.g. health & wellbeing) and qualities (e.g. robustness, redundancy), need to be considered for a comprehensive resilience assessment. Especially since the orientation of the framework depends on the focus of the organization/group that proposes it.

In ClimEmpower, we decided to use the resilience definition of the IPCC, AR6, and to base our operative resilience framework on synthesis of the best practices from ISO 37123:2019 norm, Arup framework and the best practices from RESILOC and CLIMAAX projects and Andalusian Plan for Climate Action (section 4.2, and 5.1). Applying this framework to regions will allows for an evaluation of regional resilience by identifying critical vulnerabilities, assessing interdependencies across sectors and communities, and targeting specific actions to enhance adaptive capacity.

Resilience indicators

The scientific literature strongly suggests evaluating climate resilience based on diversified sectors and include, among others, governance, and administration factors. Especially for case studies related to agriculture in smaller regions, this sector is often neglected.

Some indicators and datasets listed in the scientific literature were applied more commonly, which can be either due to the fact, that the data is easily available, e.g population density, or highly impactful for the analysis.

From the 531 indicators analysed by the project team, the conclusion can be drawn that suggested **indicators depend on the focus of the institution/project/report**. In addition, the **applicability of the indicators strongly depends on the availability of the data** needed to quantify the results. Therefore, even if some indicators are potentially useful for monitoring the change in resilience in a given context, their applicability may be questionable if the underlying data is (too) difficult to obtain. The extent of the resilience assessment and thus the investigated indicators need to be carefully decided on, weighting these two factors against available budget and resources.

Climate (indicator) services

Within WP3 the necessary resilience indicators will be made available within user centric climate services. Currently, WP3 focuses on the implementation of the CLIMAAX climate risk assessment, which represents one step in the resilience assessment and also allows the WP3 team to develop and test technology and service development process without waiting for the WP2 and WP4 teams to finish their work. As a first step towards ensuring the alignment between WP2 and WP3, the indicators relevant to CLIMAAX factsheets have been incorporated into the indicators list of WP2.

7 Next steps

Following the conclusions discussed in section 6, ClimEmpower team does not aim to set up an all-encompassing framework on resilience assessment that's valid for all regions and all use cases, but instead to empower the regions to find suitable indicator sets and that will help them define and monitor regional resilience pathways.

The role of WP2, and this deliverable, in this process is to sets up the formal framework and propose a large set of potentially useful indicators. In the next step, we need to find a good compromise in selecting the most relevant, but also suitable indicators to be implemented within ClimEmpower climate services and utilised by five ClimEmpower Case Study regions. Specific indicator sets that are useful for the regions will be decided upon in collaboration with the CoPs in WP4 and supported with climate (data, indicators) services by WP3.

This deliverable provides the base for T2.3, WP3 climate services and WP4 (Resilience Recommendations, CoP interactions). Therefore, the indicators collected are discussed within the CoP meetings (WP4) and potential further indicators from the regional stakeholders gathered. For this discussion, the aspect of short- or long-term measures to increase resilience, will be incorporated within the indicator analysis. This aspect will be included since f.i. short term measures such as stocking enough food to hold the population for 72 hours is easily achievable, while changing the employment structure (% of workforce in informal employment) or changing the building structure are indicators that need time to display significant changes.

Within the CoPs selected indicators will be discussed and input is collected on indicators already in use within the regions. These are then compared to the comprehensive list of this deliverable, and if suitable, indicators are added. To gain better understanding and widespread feedback on more indicators, a survey is set up that is sent to the regional stakeholders and distributed via social media where indicators are presented and then evaluated by the participants.

The feedback from CoP members as well as additional sources is then analysed with respect to differences between background of participants, regional affiliation, known challenges and needs based on previous CoP meetings. This analysis should support the selection of a suitable amount of the most relevant indicators to be applied by regions. Identified gaps of indicators are closed within T2.3.

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