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VALIDATED LOCAL RISK ACTIONABLE DATA FOR ADAPTATION



D1.3 Selected climate risk indicators with detailed computing metrics

Finnish Meteorological Institute

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Key concepts

Indicator

An indicator is a key figure that describes the state and development of certain entity. It can be qualitative or quantitative. The indicator aims to summarize the information contained in different datasets and produce information on the achievement of a particular state or result.

Indicator can consist of a variable, variables or a value derived from a variable, but through presentation it is more meaningful than the value of a single variable. The attachment of significance to indicators distinguishes indicators in nature, scope, and purpose from, for example, scientific measurements or individual statistical data.

Index

An index, on the other hand, is a series of aggregated or weighted variables.

Risk driver

Risk driver refers to processes or conditions that increase the level of risk by enhancing exposure and vulnerability or by diminishing resilience.

Risk drivers are broadly distinguished into climate-related hazards and non-climatic risk drivers. Essentially, they are underlying factors that shape how climate-related hazards affect human and ecological systems or how non-climate factors accelerate risk or increase the impacts of hazards.

Understanding these drivers is crucial for effective risk management and adaptation strategies.

Sources: OECD (2002), EEA (2024a), IPCC (2020)

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1. Introduction

VALORADA (Validated Local Risk Actionable Data for Adaptation, 2023–2026) project aims to increase the use of available climate-related information by regional and local administrations and enhance their adaptation to climate change. In action, this takes place by co-designing climate services that build on existing, locally sourced data and steer the transformation of these regions towards sustainable and climate-resilient development. With the tools and resources, regions and cities are better equipped to effectively make informed decisions to address local sustainability and climate challenges. VALORADA aligns with the EU's Adaptation Mission goals.

1.1 Description of task objectives

Task 1.3, which relates to this deliverable, is part of VALORADA Work Package 1: *Climate risk and status quo in climate and non-climate data services usage*. Task 1.3 begins where Task 1.1 is left off. Climate impact chains were generated to depict key climate risks within the demonstrator regions. Task 1.3 aims to identify appropriate indicators and help local demonstrators select key climate impact indicators linked to formerly identified climate risks (in Task 1.1, D1.1). Existing indicators are mapped from literature and previous projects to serve each demonstrator-specific climate risk. Criteria for allocating indicators contain the ability to capture the underlying drivers of risks, communicate the urgency of risks, and partially quantify the magnitude of these risks. Indicators will go through a validation and adjustment process within demonstrator regions. Revised indicators and the example computational metrics or workflows are transferred to WP2 and WP4 to assist in the implementation of the data catalogs and tools under development.

1.2 Deliverable scope and content

This deliverable, *D1.3 Selected climate risk indicators with detailed computing metrics,* contains general reporting of the action taken during the assigned Task and the resulting materials. The background and mapping of indicators are briefly described, in addition to lists of resulting indicators (attached as annexes). The deliverable also describes the evaluation criteria and validation method used for the indicator selection process. After an initial phase of indicator allocation, the demonstrator participants will review the appropriateness of the indicators in the implementation workshops (validation process).

The deliverable provides examples and references to potential computational metrics and methodology for the indicators shortlisted by local partners of the demonstrator regions. Please see the limitations of this section under 1.3. As per the project's strategic objectives, the deliverable also gives a short summary of potential possibilities and limitations in computing and using indicators in the next stages of the VALORADA project.

1.3 Deviation from objectives & corrective action

At the time of writing this deliverable, the validation results, which take place in implementation workshops in demonstrator regions, are still underway and not reported in this deliverable. As such, the exact indicators selected for further adjustments and development by demonstrators are not known, and the capability to define exact, detailed computing metrics is limited. Thus, computing metrics are replaced by a more general approach: examples and references of computing metrics and calculation workflows. The goal is to support the next phases of the project with these collected references.

The computational process for most indicators is progressing well within the provided workflows. For straightforward indicators (e.g., green space ratio, number of people exposed to heatwaves), the computation is

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simple when data is clear and available. However, for others, the computation methods may be more complex, and these will require collaborative efforts in the coming months. Any additional needs will be addressed on a case-by-case basis. The next steps regarding the indicators will be discussed at the General Assembly of VALORADA December 11th 2024, and are currently proposed as follows:

Next Step:

To compile the results of the implementation workshops and assess with local partners: the selected indicators, input data availability and storage, computation methods, tools, and platform to be used.

Resp: WP4, with WP1, WP2 and WP3 and the local partners.

Target date: 1st version end of December 2024, 2nd end of January 2025.

2. Mapping and defining climate risk indicators

Human-induced climate change is manifesting itself both on a climatic scale as unprecedented levels of mean global warming and on a weather scale as extreme weather phenomena that occur more often and are more intense. Climatic hazards interact with environmental and social risk drivers to cause cascading and compounding impacts on the whole society, the economy, and ecosystems. (EEA 2024a) This is well summed up in the European Climate Risk Assessment by the European Environment Agency (EEA):

"Climate risks to ecosystems, people, and the economy depend on non-climatic risk drivers as much as on the climate-related hazards themselves (EEA, 2024a)."

The so-called compound events, a combination of various climate hazards contributing to societal or environmental risk, often lead to some of the most severe weather- and climate-related impacts (Zscheischler et al., 2020). Thus, assessment of climate risks requires analysing a wide range of data and acknowledging both climate and non-climate factors. While both observed and future climate data are crucial, non-climate data play an equally important role in understanding the impacts and vulnerabilities associated with climate risks. Non-climate data provide context and help assess **adaptive capacity**, **exposure, and sensitivity** to climate hazards that determine local vulnerability. Understanding the interplay between these factors aids in conducting comprehensive climate risk assessments and defining effective adaptation strategies. The VALORADA project helps local stakeholders to benefit from combining climate and non-climate data sources to create a more comprehensive view of local climate risks.

Climate risk or climate impact indicators can be used as tools to understand changes or as metrics for evaluating progress. They describe the state and trends of key variables to inform decision and policy making. Indicators that are considered informative on the EU or national level might not prove so on a regional or local level. However, a slightly different framing of the same data could produce more appropriate indicators for the management decisions of regional and local stakeholders. In climate change related issues, there is often a conflict between global (phenomenon) and local (impacts). Therefore, especially in adaptation issues, locality is a key factor, and the perspective of the locals is at the core of the VALORADA project.

2.1 Indicators in VALORADA - role of climate and non-climate risk drivers

As previously mentioned, VALORADA aims to account for different climatic and non-climatic drivers of the local climate risks in the tools developed during the project. Climate impact chains developed in earlier stages of the project form the context for choosing relevant indicators to describe local risks. Concepts of hazard, exposure, sensitivity, and adaptive capacity are central to climate impact chains to bring out different factors contributing to the risks. Sensitivity and exposure factors increase the risk, whereas adaptive capacity can decrease it, and thus, vulnerability as an entity considers both (EEA 2024a, GIZ 2023).

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Indicators are to provide context for the following aspects of climate risks:

Hazard

Information about observed climatic conditions—e.g., temperature, rainfall, and extreme events—helps track the context within which adaptation strategies are implemented. Hazards can occur as extreme events (often described by probability or return periods) or as gradual mean changes in climate variables that, over time, alter the conditions of different societal sectors.

Exposure

These indicators reflect the presence of populations, assets, and systems in areas prone to climate-related hazards. Often, exposure depends on the location or immediate surroundings (populations and assets at risk, topography), regional patterns or distribution (population change), changes in land use, and some confounding environmental hazards (e.g., pollution).

Sensitivity

These indicators reflect the susceptibility and capacity of communities, systems, and infrastructure to withstand climate-related hazards.

Adaptive Capacity

Adaptive capacity acts in the reverse sense to exposure and vulnerability. These indicators assess the resources, systems, and strategies in place that enhance the ability of individuals, businesses, and institutions' ability to adapt to climate change's impacts. Thus, adaptive capacity indicators reflect the local capacity to respond to climate risks or take advantage of the opportunities the change brings (GIZ 2023, MA 2005). They highlight the development of skills, infrastructure, financial tools, and governance frameworks necessary to respond effectively to climate risks. Indicators monitoring adaptation often focus on processes, outputs, or outcomes, for instance, results indicating reduced vulnerability or increased adaptive capacity.

2.1.1 Climatic impact drivers (climate parameters)

Climate change affects many climate-related hazards in terms of occurrence, frequency, duration, and changing magnitude. Hazards vary between slow-onset processes (increasing mean temperature) and sudden extreme weather events (extreme heat, heatwave). (Crespi et al. 2020; GIZ 2023) Crespi et al. (2020) categorize these climate-related hazards into 1) *chronic hazards*, which refer to the slow, gradual long-term variation in average conditions often described by trends, and 2) a*cute hazards*, which are defined by their relatively short duration, magnitude, and severity. Both types of hazards go under the umbrella of **climatic impact drivers** (CID).

Climatic impact drivers presented here are based on the European Climate Risk Assessment (EEA, 2024a) and available data in European Climate Data Explorer (EEA & Copernicus) and Climate Data Store (Copernicus, ECMWF). The selection of data in European Climate Data Explorer (Crespi et al., 2020) and Climate Data Store is based on expert reviews and research and, as such, covers the most essential climate variables. They are also compatible with the Essential Climate Variables defined by World Meteorological Organisation.

Table 1. Grouping of climatic impact drivers (CIDs) (according to European Climate Risk Assessment, EEA 2024a, & Crespi et al. 2020). The same general grouping is also used in the Copernicus Climate Data Store. The table here is adapted from the corresponding table in the European Climate Risk Assessment (EEA 2024a). A more detailed table of the key climatic variables considered is in Annex 1.

CID	Description	Hazard and key climate variables
Heat and cold	Temperature effects on vegetation zones, growing season, energy demand for air conditioning and	Mean temperature Extreme heat

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	space heating; heat stress for human health, crops, ecosystems and infrastructure	Cold spells and frost
Wet and dry	Pluvial and fluvial flooding with risks to infrastructure, economy, mental health; drought effects on fire risk, crop yields and pest outbreaks; water resource risks for hydropower, irrigation and domestic water supply	Mean and extreme precipitation River flooding Aridity and drought Wildfire
Wind	Risks to infrastructure, forests and energy production	Mean wind speed Severe windstorm
Snow and ice	Risks to infrastructure and transport, winter recreation and tourism and slipping injuries	Snowfall
Marine and coastal	Water quality (e.g. toxins, acidity and temperature) impacts on marine ecology, fisheries distribution and abundance, algal formation and recreation; sea-level rise risks to coastal flooding and erosion and salinisation	Relative Sea level Coastal flooding
Compound events	Preconditioning (e.g. flooding due to heavy precipitation on already saturated soil; land use change amplifying heat/flood risk); multivariate (e.g., fluvial flooding and coastal storm surge; flooding and landslides due to heavy rain and snowmelt); temporally compounding (e.g., cumulative impacts of consecutive storms; heat- and wind-related fire risk); spatially compounding (e.g., upstream precipitation leading to downstream flooding)	

2.2.2 Non-climatic impact drivers

Non-climate data describes **non-climatic impact drivers** necessary for assessing vulnerability to climate hazards. These factors include physical, social, economic, and environmental elements and processes that shape the exposure, sensitivity, and capacity of individuals, communities, assets, and systems to hazards, such as floods and extreme heat.

- **Physical factors** include issues such as inadequate building design and construction, lack of enforcement in land-use planning, and insufficient infrastructure that fails to mitigate hazard risks.
- **Social factors** encompass issues such as poverty, inequality, social exclusion, occupation, social status, disability, age, and behavioral and psychological stressors that affect resilience.
- **Economic factors** include issues such as the lack of insurance in the informal sector, economic dependence on vulnerable industries (such as agriculture or single-resource economies), and the globalized nature of business and supply chains, which can spread risks.
- **Environmental factors** include issues such as poor environmental management, a lack of blue-green infrastructure in urban areas, unsustainable use of natural resources, and depletion of ecosystems that regulate risks.

Vulnerability is further shaped by historical, political, cultural, institutional, and natural resource dynamics that define the social and environmental landscapes in which people live. These dynamics contribute to unsafe conditions, such as residing in hazardous locations, living in substandard housing, experiencing health vulnerabilities, facing political instability, or lacking local institutions and preparedness measures. Together, these factors establish the underlying conditions that elevate the risk and impact of hazards on vulnerable populations. (UNDRR)

How do we measure vulnerability?

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Vulnerability is complex. It has many dimensions, is driven by factors at different levels, from local to global, and is dynamic as it alters under the pressure of these driving forces. Furthermore, the complex factors that make people vulnerable are not always immediately apparent.

The causes of vulnerability can form a lengthy and intricate chain, extending from underlying drivers (such as socio-economic processes) to immediate conditions (like inadequate housing quality). Tracking this chain through indicators enables identifying how vulnerability progresses and builds pressure on communities. Addressing these pressures makes reducing vulnerability at different points along the causal chain possible.

This deliverable aims to identify locally relevant indicators for the demonstrators to monitor risks and adaptation by focusing on the core components of vulnerability: hazards, exposure, sensitivity, and adaptive capacity. Integrating both climate and non-climate data is necessary for this process. The climate and non-climate impact drivers influencing the selection of indicators within the demonstrators are detailed further in the VALORADA Deliverable 1.1.

2.2 Identifying Climate Risk Indicators

Potential climate risk indicators were identified from official European sources, past projects and literature. Acknowledged sources included, for instance but not limited to, official European sources (European Climate Data Explorer, EEA & Climate-ADAPT services) and reports (EEA 2024a, EEA 2024b, EEA 2023, EEA 2019, EEA 2018, EEA 2016, ETC/CCA 2018, Crespi et al. 2020, GIZ 2023 etc.), repositories (GIZ/IISD 2013; Kenney & Janetos 2020; EU-projects INDECIS, SERV4FIRE, UrbanShift, KEKANUA etc.), and research literature (see references). The VALORADA workshops in autumn 2023 provided support for this. In Table 2, are presented the core climate risks that the demonstrator regions defined and worked with in the workshops of 2023 and that the climate impact chains in VALORADA D1.1 were based on.

Table 2. Overview of risks in designated climate impact chains and climate signals connected to them. Numbers 1 & 2 refer to different working groups within one demonstrator region in the workshops. Information in the table is based on VALORADA D1.1.

City / region	Focal risk in local climate impact chain	High temperature	Extreme precipitation	Drought
Prerov	Degradation of urban ecosystems due to urban heat and droughts	x		x
Mlada Boleslav	Extreme high temperatures on people's health in the context of urban transport	x		
Molise	Floods affecting agricultural livelihoods and rural infrastructure		x	
Toulouse & Montpellier, Occitanie	Urban warming affecting people's health	x		
Sicoval, Occitanie	Drought affecting agricultural production and rural livelihoods			x
Central Greece (Evia) 1	Wildfire affecting infrastructure	x		x
Central Greece (Evia) 2	Extreme precipitation affecting the agricultural sector		x	
Burgas 1	Urban warming on people and ecosystems	x		x
Burgas 2	Flash floods on urban and surrounding rural areas		x	
Gabrovo	Drought and wildfires affecting ecosystems and urban areas	x		x

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Climate risk indicators considered here relate to different aspects of risk, climate impacts or adaptation to climate change that are essential for managing risks. The domain of the project is wide, and demonstrator regions pose different underlying conditions and climate risks that are not limited to a certain sector. Thus, the aim was not to provide an exhaustive list of indicators but a starting point for finding and defining relevant and SMART indicators of climate risks and climate change adaptation (see 3.3 on SMART principles).

Identified indicators (Annex 2) cover all the categories of hazard, exposure, sensitivity and adaptive capacity, and were labelled with these categories for the next steps. These indicators also span various sectors, such as health, urban development, agriculture, forestry and infrastructure, and take into account entities like urban and natural ecosystems. Also, the validity of identified indicators for each demonstrator region was tentatively determined by considering the climate impact chains.

A list of hazard indicators considered useful (see 4.1) is attached in Annex 1, and the list containing indicators for exposure, sensitivity, and adaptive capacity are in Annex 2. The list features the indicator name, description, and category it belongs to. In the future steps, the selected indicators are to be tagged with additional features, e.g., related hazard, related region, data needs, theme/sector, computing and assessment, to position them into the catalogue described in VALORADA D2.3.

Workshop – brainstorming indicators locally in contextualization workshops

In the contextualization workshops held in autumn 2023 in all respective regions, local stakeholders were drafting and constructing climate impact chains on locally relevant climate risks. In the workshop, local stakeholders were encouraged to briefly brainstorm potential indicators to describe or measure different factors in their climate impact chains and identify any known local data or data source related.

After the initial mapping based on literature (reports, articles, repositories, etc.), the results of this workshop brainstorming activity were used as supporting inputs (see Annex 3). The brainstormed indicators could be used as sub-indicators as majority of them are overlapping with the indicators listed in Annex 2.

3. Selecting key climate risk indicators

Next steps of the selection process consisted of shortlisting, allocating, and validating climate risk indicators. Here are the framework and phases of the work carried out: evaluation criteria that guided the local partners to narrow down the list of indicators and SMART criteria used to validate or adjust indicators.

3.1 Evaluation criteria for indicators

In order to facilitate the validation of indicators in the implementation workshops in autumn 2024, the number of indicators needed to be reduced to a manageable total. This set of evaluation criteria aims to guide and support local partners in narrowing down the list of indicators. The involvement and ownership of local partners in this part of the process is essential, as they have the best overview of the local demonstrators' background, situation, motivations, challenges, needs, and potential local or national data sources to be used. Involvement of local stakeholders in selection process is also recommended by Leagnavar et al. (2015). Evaluation criteria are based on relevant literature, expert discussions in the VALORADA project team and the goals of Task 1.3. According to Task 1.3 description, the selected climate risk indicators should contain the ability to capture the underlying drivers of risks, communicate the urgency of risks and partially quantify the magnitude of risks.

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In the core of selecting appropriate indicators are their relevance and scope, but indicators can also be perceived from the perspective of risks related to their use and production (Lyytimäki, 2020; ETC/CCA 2018). Based on the literature, there are certain common issues and risks in the use of indicators, and the recommendations help in avoiding them.

- **Local validity creates value and increases the engagement** of the local stakeholders. Indicators are often specific to certain contexts, and to meet the needs of local stakeholders, they need to be relevant and valid in their local context (Leagnavar et al. 2015; EEA 2023; Kenney & Janetos 2020).
- **Data is the main ingredient in creating indicators**. Especially indicators related to non-climatic impact drivers depend heavily on local data. Therefore, available data to populate the indicators is crucial. Also, the accuracy and reliability of indicators are directly related to the quality and availability of data. Inconsistent or incomplete data can lead to misleading indicators. (IPCC 2020; Leagnavar et al. 2015)
- **The selected indicators should represent different aspects of risk.** Too often the range of selected indicators is narrow or/and too focused on climate and environmental data. In adaptation, the role of non-climate data and indicators based on it is essential to describe the vulnerability and its changes (= outcomes of policies or other developments). (Leagnavar et al. 2015; Kenney & Janetos 2020; EEA 2023)
- **The inadequate use or uptake of indicators,** especially to aid decision-making and adaptation action, is a commonly identified risk. If integration with policy or stakeholder engagement does not happen, their utility in driving effective and meaningful climate change adaptation will be affected. (Lyytimäki et al., 2020) Therefore, it is crucial to emphasize local validity and match indicators with local goals, actions, or projects.
- **Setting realistic goals in production** and updates of indicators. The production and update process needs to be technically feasible to ensure the continuation of monitoring risk, impact, or outcome. Also, even if an indicator is technically impeccable, it must be understandable and timely to provide actionable information for the stakeholders. (Lyytimäki et al 2020; GIZ 2023)

Recommendations for selecting local indicators, based on the abovementioned aspects, are as follows:

1. Main emphasis on relevance and local validity.
2. As producing indicators is data-driven activity, availability of data or potential to achieve needed data is a crucial criterion here.
3. Recommended that indicators selected for workshop represent all following categories that together cover both climatic and non-climatic impact drivers:
   - **Hazards** (Information about observed climatic conditions)
   - **Climate impacts,** covering exposure and sensitivity (Information about the observed impacts of climate variability and change on socioecological systems e.g., Number of people living in flood-prone areas; Total forest area impacted by wildfire per year)
   - **Adaptation process, results and adaptive capacity** (Information to help track the implementation of adaptation strategies and their outcomes, e.g., the number of public awareness campaigns on water efficiency)
4. It is recommended that indicators selected for the workshop have a link to local goals or actions. In short, an indicator and a goal/action can be matched.
5. Technical feasibility considering resources (also future ones). This includes making sure indicators work with existing tool features (WP4).

In addition, local stakeholders themselves have expressed a wish for indicators that reflect the outcomes or impacts of policymaking. Local stakeholders were encouraged to include indicators that capture adaptive capacity and the adaptation processes even though these indicators are often easily overlooked.

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3.2 Local allocation and shortlisting of indicators

The first round of shortlisting had a data-driven perspective. Here, local partners ranked each indicator with 1, 2, or 3 based on how easy or hard it would be to acquire the data required: 1 (available/easy), 2 (possibly available/requires some work to achieve or has issues to be solved) or 3 (not available/hard to achieve or process). See Figure 1 as an example of how the output looked. Ranking is based on a rough estimation and overview of data availability in the region. In practice, some data that is here ranked available could later on be ruled out, for example as it proves hard to work with due to its format. In addition, the implementation workshop evaluates the indicators in more detail and the final list of indicators is subject to change.

Indicator Name	Bulgaria	Central Greece	Czech	Molise	Occita-nie
Increase in soil degradation and desertification	2	3	1	1	2
Water usage rate in agriculture	3	3	1	3	1
Number of hectares of productive land lost to soil erosion	2	3	1	1	1
Share/percentage of agricultural crops vulnerable to climatic changes	2	3	1	1	1
Share of mixed forest of all forests and general tree composition of forests	1	1	1	1	3
Change in the threat of pests and diseases harming agriculture/forestry	2	3	1	2	3

Figure 1. A screenshot of" the catalogue*" with rankings is visible. *This refers to a first draft version (excel file) used in this project phase.

After this first phase, the list would be narrowed down based on a wider range of criteria described in 3.1. The indicators that made it through represent all the categories: exposure, sensitivity, and adaptive capacity. They are either closely related to a certain hazard (urban heat, flooding, drought, wildfire) or to a sector or theme (infrastructure, agriculture, ecosystem health).

Table 3. List of indicators that demonstrator regions selected to discuss, evaluate and validate in the implementation workshops in autumn 2024.

Indicator Name	Bulgaria	Central Greece	Czech (1)	Czech (2)	Molise	Occitanie
Disruptions to economy/livelihoods due to water scarcity, wildfire, or flooding					X	
Number of people at high risk of heat stress	X		X	X		
Urban Heat Island Effect	X		X	X		X
Changes in human thermal comfort in urban environments						X
Number and area of green spaces in urban environments	X	X	X	X		X
Share of permeable surfaces in urban environments	X		X	X		X
Number of households affected by drought			X			
Disruptions to population due to water scarcity			X			
Number of people living in flood-prone areas	X	X			X	
Number of properties flooded per year	X	X				

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Number of businesses located in areas of flood/coastal erosion risk		X				
Number of hospitals located in areas at risk from flooding/coastal erosion	X	X				
Number of critical infrastructures in areas at risk from flooding	X	X			X	
Share of flood risk area in the city or region	X				X	
Location of abandoned lands					X	X
Number of days with poor air quality due to wildfires		X				
Total forest area impacted by wildfire per year	X	X				
Distribution of (climate-sensitive) species			X			X
Distribution shifts of plant and animal species						X
Number of surface water areas subject to declining water quality due to extreme temperatures			X			
Percentage of coastline under marine protection		X				
Increase in soil degradation and desertification			X		X	
Number of hectares of productive land lost to soil erosion					X	X
Flood-related disturbances to agricultural livelihoods					X	
Drought-related disturbances to agricultural livelihoods					X	
Percentage of total livestock killed by drought					X	
Water usage rate in agriculture						X
Total sum of investments in programs for livestock protection					X	
Share/percentage of agricultural crops vulnerable to climatic changes			X		X	X
Change in the threat of pests and diseases harming agriculture/forestry			X			
Share of mixed forest of all forests and general tree composition of forests	X	X	X		X	
Annual timber losses from pests and pathogens			X			
Damages in forests due to weather-related events			X			
Seasonal distribution and change in interruptions of use in public transport (due to weather)				X		
Amount/cases of weather-related damage to road infrastructure				X		
Number of weather-related disruptions in traffic and transportation				X		
Number of weather-related disruptions in energy or electricity distribution			X	X		
Mapping of vulnerable populations	X	X			X	X
Development of tools, guides, and policies to support action on climate risks		X			X	X
Capacity building and awareness raising actions		X				X
Number of financial mechanisms identified to support climate change adaptation		X	X	X		
Funding for climate-adapted construction and refurbishment			X	X		
Percentage of transport infrastructure standards revised to consider climate risks				X		
Number of properties with retrofitted resilience measures				X		X
Uptake of early warning and disaster preparedness systems	X		X	X		

3.3 Validation method for indicators

The local stakeholders evaluate and validate indicators in the VALORADA's implementation workshops in autumn 2024. From the perspective of Task 1.3, the goals of the implementation workshops were:

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1. Reviewing a potential set of indicators to validate them or suggest necessary changes
2. Evaluating that indicators are appropriate, actionable and aid in assessing local climate risks and their underlying drivers for each local demonstrator
3. Discussing next steps required for implementing them in the VALORADA tools and the catalogue

SMART framework was proposed as the workshop working method for validating indicators. SMART is a focal and commonly used method for evaluation, which has been widely used in evaluating, for instance, adaptation projects and indicators of climate change, as well as more general adaptation or sustainability goals (Leagnavar et al., 2015; Maxwell et al. 2015). Support material describing SMART dimensions and VALORADA-relevant supporting questions was provided for workshops (Figure 2).

According to SMART criteria, a good indicator is **Specific** and **Measurable,** its data sources and implementation are **Achievable/available**, it is **Relevant** for decision-making and the risk, and it is **Timely** as being up-to-date and providing information for decision-making at the needed time. (Leagnavar et al. 2015)

It provides a framework to evaluate and discuss different important aspects of indicators from the local perspective. Here, SMART criteria were adapted and specified as follows:

- **Specific** – Clear on what is describes and to which local risks and objectives it is related to
- **Measurable** – Unit of measurement is relevant and understandable, quantifies or communicates risk (impacts), adaptation process or outcome
- **Achievable/available** – Required data and resources are available, and the level of ambition is set right (technical and decision-making-wise)
- **Relevant** – Relevant to local climate risks and decision-making, aids in managing climate risks
- **Timely** – Up-to-date, frequency of updates, in sync with local decision-making processes or needs of stakeholders

In the implementation workshop, the participants discuss through (= validate) the selected indicators and make sure they are SMART for their locale.

S Specific	M Measurable	A Achievable/ available	R Relevant	T Timely
• Is it clear what the indicator describes and measures? • Is it related to a locally relevant climate risk or adaptation objective?	• Is the unit of measurement appropriate? • Can it communicate or quantify risk, adaptation process or outcome?	• Is the needed data available? Can it be made available? • Is it feasible and realistic to produce?	• Is it locally relevant? • Does it help in planning or decision-making? (to manage climate risks)	• Does it need an update and how frequently? Is this feasible? • Timely availability for stakeholders? (when needed)

Figure 2. SMART principles and the supporting questions prepared for the implementation workshops held in Autumn 2024.

4. Computational metrics & limitations to note

This deliverable also aims to provide support in defining and identifying appropriate computing metrics for selected indicators based on references to existing tools or resources to support the computation of indicators.

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Identifying appropriate metrics for single or compound indicators can be demanding, especially for non-climate factors, as they are often applied to various sectors, scales, and circumstances (EEA, 2024a).

As a disclaimer (see 1.3), we highlight that the indicators and given references are necessarily not final and some are still missing references, as the process of validating and adjusting the indicators locally is still ongoing. Therefore, the formatting of metrics, methodologies or content (sub-indicators, involved datasets) are subject to change. In addition, 4.2 gives a short summary on limitations and challenges to note in computing and using indicators. Limitations related to a certain indicator are included in its description (4.1).

4.1 Assigning computational metrics to selected indicators

Computing climate risk or climate impact indicators consists roughly of:

1) Defining the indicator, its scope (spatio-temporal) and its goals
2) Locating data and quality check of the data
3) Processing data and defining thresholds
4) Computing and visualization

Goals of the indicator should define, what does it describe, what does it produce, to which adaptation goal or process is it related to. Thresholds are often locally determined and also depend on so called ”accepted level of risk” that may vary depending on the locale, sector and indicator in question (GIZ 2023; Nasr et al 2024). Thresholds also determine, to some extent, the scale and assessment of the indicator as they answer to: What is normal, extreme or critical? When do the unwanted impacts start to occur based on local knowledge?

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4.1.1 Key climate risks (hazards) with examples of computing metrics

4.1.2 Key risk or impact indicators with examples of computing metrics:

Disruptions to economy/livelihoods due to water scarcity, wildfire, or flooding
Number of people at high risk of heat stress
Urban Heat Island Effect / Changes in human thermal comfort in urban environments
Number and area of green spaces in urban environments / Share of permeable surfaces in urban environments
Number of households affected by drought
Disruptions to population due to water scarcity
Number of people living in flood-prone areas
Number of properties flooded per year
Number of businesses located in areas of flood/coastal erosion risk
Number of hospitals located in areas at risk from flooding/coastal erosion
Number of critical infrastructures in areas at risk from flooding
Share of flood risk area in the city or region
Location of abandoned lands
Number of days with poor air quality due to wildfires
Total forest area impacted by wildfire per year
Distribution of (climate-sensitive) species / Distribution shifts of plant and animal species
Number of surface water areas subject to declining water quality due to extreme temperatures
Percentage of coastline under marine protection
Increase in soil degradation and desertification
Number of hectares of productive land lost to soil erosion
Flood and drough-related disturbances to agricultural livelihoods
Percentage of total livestock killed by drought
Water usage rate in agriculture

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Total sum of investments in programs for livestock protection
Share/percentage of agricultural crops vulnerable to climatic changes
Change in the threat of pests and diseases harming agriculture/forestry
Share of mixed forest of all forests and general tree composition of forests
Annual timber losses from pests and pathogens
Damages in forests due to weather-related events
Seasonal distribution and change in interruptions of use in public transport (due to weather)
Cases of weather-related damage to road infrastructure
Number of weather-related disruptions in traffic and transportation & in energy or electricity distribution
Mapping of vulnerable populations
Development of tools, guides, and policies to support action on climate risks
Capacity building and awareness raising actions
Number of financial mechanisms identified to support climate change adaptation
Funding for climate-adapted construction and refurbishment
Percentage of transport infrastructure standards revised to consider climate risks
Number of properties with retrofitted resilience measures
Uptake of early warning and disaster preparedness systems

4.1.1 Key climate risks (hazards) with examples of computing metrics

Based on test version of interim data catalogue (D2.3) that considers local risks and initial list of indicators, indicators are to be tagged with following hazard categories:

- Increase in mean temperatures
- Extreme heat waves
- Changes to mean precipitation
- Extreme heavy precipitation (short-term, e.g., leading to pluvial/fluvial flooding)
- Drought
- Coastal erosion or coastal flooding

Overview of hazard indicators is attached in Annex 1. Table 2 presented the risks that local demonstrators defined in their climate impact chains, along with the most commonly associated climate signals: **high temperature, extreme precipitation, and drought.** Examples of relevant climate variables to describe these hazards are presented in table 4. In the case of drought, climate impact chains refer mostly to meteorological drought, characterized by prolonging low precipitation, or to agricultural drought consisting of low rainfall, decreased soil moisture and resulting water stress for crops.

In addition, wildfires are mentioned as a hazard in couple of climate impact chains. Wildfires as a phenomenon most often results from high temperatures and low precipitation leading to drought and optimal conditions for a wildfire to break out. Therefore, the important key climate variables for wildfires are present and some additional variables, specific to wildfire danger, are included in Annex 1.

Climatic indicators in the annex 1 are commonly used and relevant variables to describe climatic impact drivers and, as the selected hazard indicators follow the approach of European Environment Agency (EEA) European Climate Data Explorer and Copernicus Climate Data Store (CDS). Indicators/indices listed in Annex 1. are available through European Climate Data Explorer and CDS, though spatial and temporal scale varies.

Table 4. Examples of climatic variables to assess effects of heatwaves, extreme precipitation events or drought.

Variable name	Unit	Resolution	Description
The Climatological	Number of days	NUTS 0, 1 & 2	The index counts the number of days in a year within prolonged periods of unusually high temperatures. The higher/lower the

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Heatwave Days index			value, the longer/shorter the heatwave. A climatological heatwave is a period of at least three consecutive days exceeding the 99th percentile of the daily maximum temperatures of the May to September season during a reference period.
Apparent Temperature Heatwave Days	Number of days	NUTS 0, 1 & 2	The index gives the number of days with prolonged periods of simultaneous extreme humidity and heat conditions. The apparent temperature is a measure of discomfort due the combination of heat with high humidity based on physiological studies on evaporative skin cooling. The higher/lower the apparent temperature, the higher/lower the discomfort.
Tropical Nights	Number of days	NUTS 0, 1 & 2	The Tropical Nights index is the count of days when daily minimum temperature remains above 20°C. High values of minimum temperature cause physiological discomfort during periods of high temperatures by preventing body temperature to cool-off during the night. A higher value indicates more Tropical Nights.
High Universal Thermal Climate Index (UTCI) days	The number of days when UTCI remains above 32°C	NUTS 0, 1 & 2	The UTCI is an equivalent temperature (°C) and is a measure of the human physiological response to meteorological conditions that also takes into consideration the clothing adaptation of the population in response to outdoor temperature. It is based on four surface variables: air temperature, relative humidity, wind speed and mean radiant temperature. A higher value indicates more High UTCI days.
Extreme Precipitation Total	mm	NUTS 0, 1 & 2	The total sum in a year of daily precipitation values exceeding the 95th percentile of the reference period (mm). A higher/lower value indicates more/less extreme precipitations.
Extreme Precipitation Days	Number of days	NUTS 0, 1 & 2	The count of days in a year with daily precipitation exceeding the 95th percentile threshold of rainy days over a reference period, here the 1981-2010 period (day). A higher/lower value indicates more/less frequent extreme precipitations.
Meteorological Drought Duration	Number of months in a year	NUTS 0, 1 & 2	The count of months in a year with anomalously low precipitation conditions based on the 3-month Standardised Precipitation Index (SPI-3) relative to a reference period, here 1981-2010 (month).
Meteorological Drought Magnitude	-	NUTS 0, 1 & 2	The cumulative severity of drought events in a year based on the 3-month Standardised Precipitation Index (SPI-3) relative to a reference period, here 1981-2010 (dimensionless). A higher/lower value indicates shorter/longer droughts Magnitudes.

In addition, Climate Data Store has additional datasets of climate indices and projections that can prove helpful in next stages of VALORADA. Examples of such are:

Global bioclimatic indicators (also described in VALORADA D4.3)

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- Present day: (Wouters, 2021)
  Wouters, H.: Downscaled bioclimatic indicators for selected regions from 1979 to 2018 derived from reanalysis. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.fe90a594 (Accessed on 14-11-2024), 2021.
- Future: (Wouters et al., 2021)
  Wouters, H., Berckmans, J., Maes, R., Vanuytrecht, E., De Ridder, K.: Downscaled bioclimatic indicators for selected regions from 1950 to 2100 derived from climate projections. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.0ab27596 (Accessed on 14-11-2024), 2021.

Fire danger indicators

- Copernicus Climate Change Service, Climate Data Store, (2020): Fire danger indicators for Europe from 1970 to 2098 derived from climate projection. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.ca755de7 (Accessed on 14-11-2024)

Agroclimatic indicators

- Wit, A., Elhaddad, A., Meyer zum Alten Borgloh, S., Turdukulov, U., Hutjes, R., (2022): Crop productivity and evapotranspiration indicators from 2000 to present derived from satellite observations. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.b2f6f9f6 (Accessed on 14-11-2024)
- Copernicus Climate Change Service (2019): Agroclimatic indicators from 1951 to 2099 derived from climate projections. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.dad6e055 (Accessed on 14-11-2024)

Example workflows to calculate and assess data for key climate risks

Handling, processing and calculating indexes from climate data can be challenging. The ongoing CLIMAAX Horizon Europe project (website) has developed an excellent handbook (website) with tools and data sets for regional climate risk assessment. The methods presented in the CLIMAAX handbook are based on literature reviews and best practices of climate risk assessment workflows and as such, it is a valuable and up-to-date resource and a practical starting point for calculation of climate metrics. This also supports to goal of VALORADA to cooperate and find synergies with its sister projects, such as CLIMAAX.

The handbook provides step-by-step instructions with examples on how to derive climate risks for the present and the future climate based on local climate data or European EURO-CORDEX climate scenarios data. In addition, the CLIMAAX toolbox provides direct links to selected Copernicus Climate Data Store (website) datasets for specific variables like heatwaves, extreme precipitation, and drought. It also contains links to the Climate Adapt portal(website) from which details of selected data are summarized in Table 4.

Additional references for drought

In evaluation of drought, various different indexes, such as SPI and SPEI, can be utilised. The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage (Keyantash & National Center for Atmospheric Research 2023). For example, datasets in table 4 describing meteorological drought duration and magnitude are based on Standardised Precipitation Index (SPI-3).

The Standardised Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardised Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought.

ERACS project called SERV_FOR_FIRE had pilot areas in the Mediterranean, for instance in Greece and Italy, and in the project a software was developed that could be used for the computation of Standardized Precipitation Evapotranspiration Index (SPEI) time series at a global scale as well as for the trend analysis. Reference for the

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workflow: Di Giuseppe E., Quaresima S., & Pasqui M. (2019, June 28). edidigiu/DROUGHT-SPEI: SPEI-Trend (Version v1.0.0). Zenodo. http://doi.org/10.5281/zenodo.3260197 & https://zenodo.org/records/3260197. Journal article behind the method: https://doi.org/10.3390/hydrology6040084

4.1.2 Key risk or impact indicators with examples of computing metrics

Key climate risk (impact) indicators listed here describe not only climatic risk but the aspect of exposure, sensitivity, adaptive capacity or a combination of them. In the calculation phase, indicators might need to be further divided into parts to define sub-indicators and designated datasets for computing. Also, some of the indicators here depict different aspects of the same risk, and thus, could be combined (layered).

A common way of quantifying and communicating climate vulnerability is to calculate composite indices from indicators and visualising these as maps. In addition, maps can present locations of assets or vulnerable targets or ranges defining distance (e.g. access) to certain assets or targets. Thus, the general method ”Spatial assessment of the datasets” in the descriptions of indicators refers to GIS-based methods used to visualise and analyse the indicator output, but the exact library is to be further specified by WP4 experts to best fit the existing tool infrastructure (e.g. Python-based Geopandas or other).

<table>
<tr><td>Disruptions to economy and livelihoods due to water scarcity, wildfire or flooding</td><td>Could describe the losses, number of disruptions to certain livelihoods or sectors, number of occupations (and people working in them) vulnerable to or been affected by water scarcity, wildfires, or flooding.</td><td>Sensitivity</td></tr>
<tr><td colspan="2">Defining selection of 1) hazard(s), 2) unit of assessment, 3) livelihoods and/or sectors. Spatial assessment of the datasets describing selected factors.

Grouping/assessment: by hazard (and magnitude), by unit, by livelihood/sectors</td><td>General reference: EEA 2024b (chapter 3)</td></tr>
<tr><td colspan="2">Data needs: Data on weather and climate related disruption to economy. Should contain information to which weather/climate-related event it is related to and/or could be categorized based on respective hazards.

Requires information of locally relevant occupations and livelihoods that are affected by the selected hazard. Example: farming (yield losses, decreased in land value), tourism (water scarcity, wildfire threat, loss of recreational activities)</td><td rowspan="2">Unit: losses (€), number of disruptions and their locations, number of businesses or workers affected</td></tr>
<tr><td colspan="2">Limitations: Important to note in assessment, if the data is not well categorized based on cause, disruptions can be hard to pin on certain hazard or hazard’s role in overall disruption might be challenging to assess.</td></tr>
</table>

<table>
<tr><td>Number of people at high risk of heat stress</td><td>Describes risk areas for heat stress and the number of population residing there. Provides better understanding if additional risk factors (vulnerability) such as old or very young age, chronic health conditions, low income, low level of education etc. among population are considered.</td><td>Exposure</td></tr>
<tr><td colspan="2">Summation of people exposed in certain area and spatial assessment of the data.
Requires definition of “high risk” (local climatic threshold, level of exposure, certain demographic groups weighted).</td><td rowspan="3">References:
Li et al. 2023 (literature review on social vulnerability factors on health) & EEA 2018: 5.3)

Social vulnerability to climate change in Helsinki metropolitan area (Kazmierczak 2015) (incl. workflow and data processing descriptions)</td></tr>
<tr><td colspan="2">Data needs depend on the focus, examples: Areas exposed to heat stress; Population density; Pre-existing vulnerability mapping or Heat stress maps; Location and number of people with cardiovascular/respiratory illnesses or other vulnerability factors

Climate data: Hot days, Cooling degree days etc.</td></tr>
<tr><td colspan="2">Limitations: The number of people in risk does not solely depend on climate factors or surrounding urban environment and being exposed to it, but also demograhic and social factors (mobility, people moving to other regions and cities).</td></tr>
</table>

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Urban Heat Island Effect	Climate change affects the urban climate in a way that can result in severe thermal stress with effects on people's health (well-being, mortality, morbidity). The Manifestation and magnitude of the heat island effect is not only due to changing climatic parameters but also influenced by architecture, building density and materials, urban planning and green spaces etc.	Exposure

Simple method:
Subtracting temperature of the surrounding areas minus temperatures in urban centres. This gives a rough idea of the strength of the Urban Heat Island Effect which can be taken into account in analysing, e.g., climate change future projections. **Unit**: Celsius degrees

More complex methods:
In order to compute an UHI_{max} and quantify the meteorological variables, observations from rural areas surrounding the city are also needed. Therefore, observations of temperature, wind, solar radiation, rain and relative humidity from local weather observation stations are required.

Basic data needs: Temperatures of different points in the urban centre and in the surrounding areas; Meteorological datasets* of local UHI_{max} or data from urban modelling or temperature scans; Suitable satellite images; Land cover/land use data helpful (green areas, blue areas, density of buildings)

Example references:
Estimation of the urban heat island for UK climate change projections https://journals.sagepub.com/doi/10.1177/0143624410365033

A diagnostic equation for the daily maximum urban heat island effect for cities in northwestern Europe, Theeuwes et al. (2016), https://doi.org/10.1002/joc.4717

Estimating local-scale urban heat island intensity using nighttime light satellite imageries, Sun et al. (2020), https://doi.org/10.1016/j.scs.2020.102125

Limitations: The manifestation and magnitude of the heat island effect is not only due to changing climatic parameters but also influenced by architecture, building density and materials, urban planning and green spaces etc. If meteorological/urban datasets (*) do not already exist, computing is resource-heavy and demanding. *Methodology needs further reviewing in terms of complexity and what could be achieved within project resources. There are also several ways to approach Urban Heat Island: meteorological data, satellite images etc.*

Changes in human thermal comfort in urban environments	Urban thermal comfort is a critical aspect of city livability, influenced by complex interactions between the built environment and meteorological factors. Urban design strategies, such as implementing cool materials and urban greenery, can impact thermal comfort. Individual capacity, e.g. access to air conditioning or cooling, plays a role	Sensitivity

Methodology:
There are many indexes to measure heat stress and human thermal comfort (Blazejczyk 2012), but Universal Thermal Climate Index (UTCI) is highly sensitive to changes in temperature, humidity, wind speed, and solar radiation. It provides a nuanced assessment of thermal comfort across various climates. UTCI is suitable for both indoor and outdoor environments, making it versatile for urban planning and public health assessments.

Calculation: Based on a complex regression model that incorporates multiple environmental factors. There are existing datasets of UTCI available in, e.g., Climate Data Store.

Data needs: climate data (temperature, humidity, wind speed, and solar radiation), or existing datasets.

Reference:
Di Napoli C., Barnard C., Prudhomme C., Cloke HL and Pappenberger F. (2020): Thermal comfort indices derived from ERA5 reanalysis. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.553b7518

Limitations: Calculation of UTCI locally is more complex, compared to simpler indices, e.g., Heat Index (HI) or Apparent temperature (AT), and requires specialised tools and familiarisation with methods, thus use of national or European existing datasets is recommended. Other limitations of UTCI can be interpretation challenges (what the values represent) and using UTCI in extreme conditions (very high or low temperatures) may yield unreliable results and extrapolation errors. The temporal and spatial resolution of the available data might limit the use.

Does not describe socio-economic factors of human thermal comfort, e.g. access to air conditioning, water bodies or green spaces, but these and information on building and population density and land use could be accounted for.

Number and area of green spaces in urban environments	Urban green spaces are a key component of urban resilience to climate change. Could also be adopted as area of green space per citizen, ratio of green spaces in different urban environments or areas or expanded to include connectivity of greenspaces.	Exposure
Share or ratio of permeable surfaces in urban environments	Describes the share of permeable surfaces in urban environment, related to risk of pluvial flooding. Can also be related to human comfort during heatwaves.	Exposure

Methodology:

Calculating numbers, areas (size) and shares/ratios. These could also be calculated in comparison to population (per capita). Spatial assessment of the datasets describing selected factors.

References:

Land degradation/Green space-related methodology repository by World Resource Institute & UrbanShift-project:

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Sub-indicators could include for example: Percent of vegetation land based on NDVI threshold (land that is vegetation (NDVI threshold > 0.4)) Percent of built area with tree cover Percent of built area with vegetation (% of built area with vegetation based on NDVI threshold) Share of (public) green area, share of are with vegetation, share of canopy area Access to green space (% of the population with access to a public green space nearby (less than 10 minute walk))	https://github.com/wri/cities-urbanshift/tree/main/baseline-indicators (ipynb-files, IPython Notebook; includes subindicators and used datasets)
Data needs: Land use data from the city/region or freely available digital maps; satellite imagery from which green areas can be recognized	

Number of households affected by drought	Drought impacts households, e.g., through water shortages, restrictions in water use or dependence on alternative water sources (e.g. the number of days per year with water use regulation on certain areas, number of households there). It can affect food security or cause economic strain increased costs (water, electricity). Indicator can also just describe the number of households in a high risk area.	Exposure
Summation of information and spatial assessment: Map of areas declared as affected by drought and calculating the number of households present within drought-declared areas.		**References**: GIZ/IISD 2014, EEA 2024b (chapter 3)
Data needs: Data on areas that are affected by drought (e.g. observations, climate or index data); local demographic information (number of households, people, livelihoods) on areas;		
Limitations: This indicator could be completed with other indicators to assess households' vulnerability to multiple hazards (not just drought) since people are often affected by a combination of stresses and shocks.		**Unit:** number or %

Disruptions to population due to water scarcity	Describing, for example, the number of days per year with water use regulation or a more complex index of water scarcity. In the EU since 2010 water scarcity situation has been a worsening. Compounded with the fact that climate change is expected to further increase the frequency, intensity and impacts of drought events, makes it somewhat unlikely that water scarcity will reduce by 2030. Additional effort is needed to ensure sustainable water use.	Sensitivity
Spatial assessment of the datasets describing selected factors. Water scarcity could be measured by: 1) Local statistics and/or meteorological observations. 2) EEA has measured this by the water exploitation index plus (WEI+), which is documented in the related reference. In addition to index, local data is needed about the impacts (disruptions). Future aspects can be measured through 3) Future climate projections, including socio-economic projections. 4) With various sub-indicators, e.g., percentage of water demand being met by existing supply & estimation of future demand and supply		**References:** EEA indicator (methodology, uncertainties, further references) General reference: EEA 2024b (vulnerability and exposure to water stress or scarcity) Also see EEA 2024b (chapter 3)
Data needs: 1) Data on disruptions closely related to water scarcity, e.g., number of days per year with water use regulation, disruptions in tap water distribution 2) Climate data, data on water abstraction by source (surface water and groundwater) and water abstraction by sector with temporal and spatial gaps (check reference)		**Unit:** number of disruptions or days with disruptions, area affected (% or area size), population affected (% or number), WEI+ as %
Potential limitations: Method 2: Computing of WEI+ for small regions and resources needed for calculation. Water scarcity is not only caused by drought or low precipitation, but by how water is consumed in the society (agricultural practices etc.) and how the consumption varies (e.g. tourism)		

Number of people living in flood-prone areas	A high number of people living in flood prone areas shows a high exposure to flood risks. Could be completed with other indicators to assess the impacts of floods on people living in flood prone areas (in terms of socio-economic impacts).	Exposure
Methodology/computing: Summation of information and spatial assessment of the datasets: Map of areas declared as flood-prone, based on historic records, flood risk map or analysis of future flood risk, and calculating the number of people present within area.		References: Overview on indicators used to characterise flood vulnerability, Moreira et al. (2021), https://doi.org/10.5194/nhess-21-1513-2021

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Assessed by area unit (number, or ratio from densest to least dense), by socio-economic groups.	Malgwi et al. (2020), https://doi.org/10.5194/nhess-20-2067-2020 Flood Risk Mapping Worldwide: A Flexible Methodology and Toolbox, Glas et al. (2019), https://doi.org/10.3390/w11112371
Data needs: flood zone maps; demographic data on population living in these areas and population density	
Limitations: This indicator could be completed with other indicators to assess the impacts of floods on people living in flood prone areas (in terms of socio-economic impacts), see for example Moreira et al. (2021). *If flood risk maps or similar analysis does not exist, computing can be resource-demanding.*	

Number of properties flooded per year	Climate change increases the frequency and intensity of extreme weather events such as floods. It can also change the location and timing of floods.	Exposure

Methodology/computing: Summation and geospatial assessment of the datasets: Map of areas declared as affected flood, based on historic records/statistics, flood risk map or analysis of future flood risk, and calculating the number of properties present within area. Assessment: By area, by types of properties (businesses, residential etc.)	**References**: Flood Risk Mapping Worldwide: A Flexible Methodology and Toolbox, Glas et al. (2019), https://doi.org/10.3390/w11112371 QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps
Data needs: Flood affected areas or Statistics of properties flooded per year, Number of properties located within flood-affected areas	
Potential limitations: Attribution issue: the number of properties flooded per year may be due to other non-climatic factors (e.g. deforestation, rapid population growth, wetland degradation) or a combination of climatic and non-climatic factors. *If flood risk maps or similar analysis does not exist, computing can be resource-demanding.*	

Number of businesses located in areas of flood/coastal erosion risk	Smaller number of businesses located in areas of flood/coastal erosion risk shows a reduced exposure of businesses to those risks. This includes also number/locations of industries vulnerable to flooding (that can cause a further threat, e.g., of chemical dispersion).	Exposure

Methodology: Overlaying flood risk (geospatial assessment, GIS) with the locations of businesses. Identification and summation of businesses located within areas. **Grouping/assessment:** By business type and size (€ or employees), by region, by sector	**References**: Flood Risk Mapping Worldwide: A Flexible Methodology and Toolbox, Glas et al. (2019), https://doi.org/10.3390/w11112371 QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps
Data needs: Location of current and future potential flood/coastal erosion risks; location of businesses; types of businesses (if further vulnerability is to be evaluated)	
Limitations: This indicator only assess the exposure of the businesses to flood/coastal erosion risk. It could be completed with other indicators to assess the vulnerability of the businesses to flood/coastal erosion risk. *If flood risk maps or similar analysis does not exist, computing can be resource-demanding.*	**Unit:** number

Number of hospitals located in areas at risk from flooding/coastal erosion	Essential services, such as hospitals, health care centres, nursing homes and similar, should be located outside of risk areas to prevent them from being damaged and/or destroyed from floods/coastal erosion. Could be completed with other indicators to assess the vulnerability (i.e. sensitivity and adaptive capacity) or by including other facilities typically residing vulnerable populations (e.g. nursing homes, kindergardens, schools)	Exposure

Methodology: Geospatial assessment (GIS) of the locations of critical infrastructure and overlaying flood risk map to identify, which hospitals, health care centres, nursing homes and similar, fall within high-risk areas. QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps).). **Grouping/assessment:** By region, by types of facilities, by types of climate hazards	For references, see Number of critical infrastructures in areas at risk from flooding and Number of

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Data needs: Location and number of hospitals in a specific area; Distribution of flooding/coastal erosion risks (flood/coastal erosion risk maps); Information on emergency response plans in place or resilience measures; Information on the profile of health care facilities to locate high priority or high risk facilities	people/properties on flood-prone area
Limitations: This indicator only assess the exposure of hospitals to flood/coastal erosion risk. It could be completed with other indicators to assess the vulnerability (i.e. sensitivity and adaptive capacity) of hospitals to flood/coastal erosion risk. *If flood risk maps or similar analysis does not exist, computing can be resource-demanding*.	

Number of critical infrastructures in areas at risk from flooding	Essential services, such as hospitals, power plants, emergency service providers, should be located outside of risk areas to prevent them from being damaged or destroyed from floods or coastal erosion or being rendered incapable of action in case of flooding.	Exposure
Methodology: 1. Identifying the critical infrastructures locally 2. Geospatial assessment (GIS) of the locations of critical infrastructure and overlaying flood risk map to identify, which infrastructures fall within high-risk areas. QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps). **Additional features:** **Vulnerability assessment** Spatial assessment could be completed with assessment of resilience and vulnerability (i.e., sensitivity and adaptive capacity) of the identified infrastructures. Factors to consider are, for example, whether there is an emergency response or preparedness plan in place for the infrastructures (lowers vulnerability) or if structures are particularly vulnerable due to structural integrity, elevation, proximity to water bodies, based on historical flood data (increases sensitivity). **Future analysis** Analysis of trend of the flooding and coastal erosion risk based on modelled flood or water level projections (requires existing data and projections).		**Reference:** Cataloging and Testing Flood Risk Management Measures to Increase the Resilience of Critical Infrastructure Networks (2024), https://doi.org/10.3390/smartcities7050117 Flood Risk Mapping Worldwide: A Flexible Methodology and Toolbox, Glas et al. (2019), https://doi.org/10.3390/w11112371 QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps
Data needs: Spatial data on location and number of critical infrastructures in a specific area of risk; Flood and/or coastal erosion risk maps; Information on the preparedness measure to add weight (optional). *If flood risk maps or similar analysis does not exist, computing can be resource-demanding*.		**Unit**: number, spatial hotspots

Share of flood risk area in the city or region	Describes the location and/or share of flood risk areas within city or region. Capacity to prepare for flood events could then be focused on the risk areas, or future land use planning could take this information into account.	Exposure
Calculating shares of risk areas from the entire assessed area and spatial assessment of the high-risk areas. **Data needs**: Flood risk map, data on land use (e.g. residential, commercial areas), area sizes (entire area, risk areas). *If flood risk maps or similar analysis does not exist, computing can be resource-demanding*. **Unit**: % or in number (area)		**References**: Flood Risk Mapping Worldwide: A Flexible Methodology and Toolbox, Glas et al. (2019), https://doi.org/10.3390/w11112371 QGIS plugins, for example Flood Risk and SAGA GIS can help analyse flood data and create risk maps

Location of abandoned lands	Abandoned or mal-maintained land areas pose an increased wildfire risk.	Exposure
Simple spatial indicator to recognize the locations of abandoned lands that could pose a wildfire risk. **Assessment:** by region; by previous use; recognized land areas could be given a "risk rating" based on more detailed assessment of surrounding areas, vegetation and the number of days with high fire weather inxex values.		**Reference**: Salis et al. 2022, https://doi.org/10.3390/land11111942
Data needs: Location of abandoned properties or parcels; type of previous use		**Unit**: location, area size, ranking

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Number of days with poor air quality due to wildfires	Poor air quality poses a health risk and worsens the effects of heat on people's health. Warming climate can increase the risk and occurrence of wildfires that can lead to more poor air quality days.	Sensitivity
Summation, accumulation and trend to compare years or different areas.		**General reference**: EEA 2018, EEA 2024b
Data needs: Data on days with poor air quality with concurrence of wildfires (from national or local met. and environm. agencies)		

Total forest area impacted by wildfire per year	Increasing temperature due to climate change can lead to increase wildfire with negative impacts on forest resources, local populations and tourism. This can also lead to permanent forest loss and other compounding impacts.	Sensitivity
Enumeration and spatial assessment. Grouping/assessment: By types of forest area		**References**: GIZ/IISD 2014, Global Forest Watch dashboard
Data needs: Number of wildfires per year; number of forest area damaged by wildfire per year		
Potential limitations: Attribution issue: wildfires may be due to various factors not just increasing temperatures due to climate change (e.g. land use changes)		**Unit**: hectare, %

Distribution of (climate-sensitive) species	Climate change can shift the geographic ranges of some species and alter biodiversity. Vanishing or decreasing number of climate sensitive species indicates ongoing change in ecosystem.	Exposure
Enumeration/count: Types of and spatial location of climate sensitive species. Spatial assessment (see UrbanShift) Grouping/assessment: by regions, by species, by population change		**Reference**: Biodiversity-related indicators in methodology repository by World Resource Institute & UrbanShift-project: https://github.com/wri/cities-urbanshift/tree/main/baseline-indicators (ipynb-files, IPython Notebook; includes subindicators and used datasets)
Data needs: Knowledge of locally relevant sensitive species and their habitats. Data on conservation areas. This indicator could be completed with other indicators to capture changes of species' composition, and functions.		
Limitations: This indicator could be completed with other indicators to capture changes of species' composition, and functions.		Unit: Hectar, population size

Distribution shifts of plant and animal species	Climate change is projected to shift the geographic ranges of some species and alter biodiversity. Distribution changes of several hundred kilometres projected over the 21st century. These impacts include northwards and uphill range shifts, as well as local and regional extinctions of species.	Exposure
Enumeration/count: Types of and spatial location of climate sensitive species. Spatial assessment (see UrbanShift) Grouping/assessment: by regions, by species, by trend/change		**General reference:** EEA 2016, **Reference**: Biodiversity-related indicators in methodology repository by World Resource Institute & UrbanShift-project: https://github.com/wri/cities-urbanshift/tree/main/baseline-indicators (ipynb-files, IPython Notebook; includes subindicators and used datasets)
Data needs: Knowledge of local plant and animal species relevant to ecosystems and ecosystem services. Habitats and change in them. Local protected and conserved areas. Fragmentation and		

Number of surface water areas subject to declining water quality due to extreme temperatures	Extreme temperatures in the context of climate change can lead to water quality degradation. Vulnerability maps can help identify hot-spots and support decision-making.	Sensitivity
Geographical Information System (GIS) (overlapping maps of surface water areas exposed to extreme temperatures and those highly vulnerable to extreme temperatures) Grouping/assessment: By region, by type of surface water (running or other). Unit: number, surface area		**Reference**: GIZ/IISD 2014, EEA 2024b, EEA: Ecological status of surface waters in Europe
Data needs: Geographical location of surface water area in the country; number of surface water areas exposed to extreme temperatures; number of surface water areas vulnerable to extreme temperatures		

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Potential limitation: This indicator only focuses on surface water quality (not quantity) due to one climate hazard (i.e.extreme temperatures).

Percentage of coastline under marine protection	Higher temperatures and more GHG emissions lead to higher water temperatures and acidification levels in the sea that disturb marine habitats. By protecting marine zones their ecosystem services and biodiversity can be conserved which can contribute to enhance their resilience to climate change.	Adaptive Capacity
Numerator = total number of hectares of marine zones officially protected + Denominator = total number of hectares of territorial sea. Visualisation helps in assessment.		**General reference**: GIZ/IISD 2014, EEA 2024a
Data needs: Total number of hectares of marine zones officially protected, total number of hectares of territorial sea		**Unit**: Hectare, km, %

Increase in soil degradation and desertification	Describes either future risk based on climate projections and possibly land use. And/or combines projections with local information on high-risk areas of soil degradation, increased erosion (including agricultural lands) and desertification due to, e.g., their current state, type of vegetation, activities such as agriculture or changes in land use.	Sensitivity
Data needs and assessment: Mapping areas of risk and data on the status of the risk areas. (continuity to see trends)		References: GIZ/IISD 2014, EEA 2023: Soil monitoring in Europe

Number of hectares of productive land lost to soil erosion	Stable soils have great value in helping people adapt both in terms of agricultural productivity and ability to deliver other beneficial services (e.g. reduced flooding).	Sensitivity
Mapping areas of risk and data on the status of the risk areas. (continuity to see trends)		References: GIZ/IISD 2014, EEA 2023: Soil monitoring in Europe
Data needs: Number of hectares of productive land in the country and/or region; number of hectares of productive land lost to soil erosion		
Potential limitations: Attribution issue: soil erosion may be due to a combination of factors (e.g. deforestation) and not just climate change.		**Unit**: hectar

Flood-related disturbances to agricultural livelihoods	Refers to the disruptions and challenges to agricultural sector due to floods. These disturbances can be, e.g., crop failure (submerge, root damage and rot), loss in yield and seedlings, rising costs and economic strain, soil degradation, delayed planting and harvesting.	Sensitivity
Drought-related disturbances to agricultural livelihoods	Refers to the disruptions and challenges to agricultural sector due to prolonged periods of low rainfall or water shortages. These disturbances can occur as, e.g., crop failure (especially "cash crops" that farmers rely on for livelihood), reduced yield, loss of seedlings, rising costs. Could also be measured in loss of income, increase in debt or unemployment.	Sensitivity
Methodology: Selecting sub-indicators, for example crop types grown in target area and their sensitivity to flood or drought, crop failure as %, loss in yield in €, and spatial assessment of the datasets. Assessment: by regions, by hazard, by crop type, by loss type (discturbance) **Combining with hazard Indicators** measuring the frequency, intensity, and duration of flood and drought events and future projections. Analysing historical data to identify patterns in agricultural losses related to drought.		
Data needs: data on flood and drought-related damages or disturbances; data on yields or yield/seedling losses (amount, worth); data on losses of income; crop types grown in target area and their sensitivity to flood or drought; climate data (see above) Floods: distance to the river, topography (elevation), land use (Chen 2022).		

Percentage of total livestock killed by drought	Describes the loss of livestock due to drought or related environmental conditions. Drought can impact livestock both directly (e.g. changes in water and fodder availability) and indirectly (e.g. increased livestock diseases), with negative impacts on livelihoods and economic sectors.	Sensitivity
Numerator = number of livestock killed by drought; Denominator = total number of livestock; Moving Average: Numerator = sum of annual measurements over the period; Denominator: number of years in the period.		**Reference**: GIZ/IISD 2014, EEA 2019

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Grouping/assessment: as a total, by types of livestock, by region	
Data needs: Total number of livestock in target area; Total number of livestock killed by drought in target area; Number and severity of droughts over a period of time; Insurance records	**Unit**: % in certain areas
Possible limitations: Other factors than climate change may contribute to livestock death, even during drought periods (e.g. health of livestock).	

Water usage rate in agriculture	Important indicator in understanding water needs and need for more efficient practices within agricultural systems especially in the context of climate change, where water availability is increasingly uncertain. Measures for example the amount of freshwater utilized in agricultural practices, expressed as a ratio of total water consumption, or	Sensitivity
Assessment by: Irrigated area, areas of high water consumption, percentage of **water demand** being met by existing supply, differences between regions		**References**: GIZ/IISD 2014, EEA 2019.
Data needs: Agricultural water usage data from locals or agricultural agencies; and/or irrigated/irrigable agricultural land; Locally grown crops and their water needs; volume of water supplied and water demand (in cubic metres)		

Total sum of investments in programs for livestock protection	Livestock is an important source of livelihood and income. Investing in adaptation measures increase the farmers' adaptive capacity can offset the negative repercussions of climate change.	Adaptive Capacity
Summation and assessment, for example, by region, by types of livestock or farms.		**Source/reference:** GIZ/IISD 2014, EEA 2019
Data needs: Total sum of investments in the programme for the protection of livestock before and now		**Unit**: amount in local currency
Limitations: This indicator does not capture the quality of the programmes that are set up to protect livestock or the effectiveness of the investments (= targeted to most vulnerable groups?)		

Share/percentage of agricultural crops vulnerable to climatic changes	Measures the proportion of agricultural crops that are susceptible to the impacts of climate change, including shifts in mean temperature, precipitation patterns, and the increased frequency of extreme weather events. It provides insights into the resilience of agricultural systems and highlights the crops most at risk of yield loss or failure due to changing climatic conditions. Changing crops to more resilient ones can increase resilience of agricultural sector and enhance food security.	Sensitivity
Simple method: Defining locally relevant crops, their degree of climate vulnerability or resilience and which hazards are considered. The percentage reflects how many crops are likely to be adversely affected by climate-related factors and helps stakeholders identify areas needing urgent attention and prioritize action. Prioritization by assessing variations between areas spatially (GIS). **Additional features**: Factors of local context: impact severity (possible yield loss, economic importance of crops), adaptation potential (availability of resilient variables, cost), and soil type, water availability, farmer knowledge and capacity (general context). Factors can be adjusted to fit the locale. Pursuit prioritization by ranking crops, for instance, assign scores for impact severity (1-5), adaptation potential (1-5), and local context (1-5). Total score can help prioritizing crops.		**References**: Copernicus CDS: Agroclimatic indicators, crop productivity and evapotranspiration indicators. Ceglar et al. 2020. "Clisagri: An R package for agro-climate services": Modelling-approach (resource heavy), but also describes sub-indicators and assessment (quantifying the risks). Wirenh et al. 2015: Assessment of composite index methods for agricultural vulnerability to climate change General reference: EEA 2019
Data needs: Data on locally cultured crops and information on climate sensitivity of these plants (growing season, water needs, temperature resilience); Information about newly introduced more resilient crops and/or crop diversity; Land use and agricultural zones where crops are produced; Information on non-climate aspects (economic importance of crops, farmers capacity and knowhow)		**Unit**: share (%), hectars

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Change in the threat of pests and diseases harming agriculture/ forestry	Changing climate is expected to significantly impact agricultural insect pests in Europe by making the climatic preconditions more suitable for certain pests to reproduce and diseases to spread. Vulnerable forests can be prone to diseases in changing climate. Rising temperatures are likely to cause poleward range shifts and increase in the number of generations for many pest species, and to increase prevalence and severity of crop pathogens and fungal infections in some crops. Also new invasive pests and diseases might arrive to Europe.	Sensitivity
Defining the sector, relevant threat in question (see references, if needed) and climatological prerequisites for the pest or disease occurring more often. Calculating the changes in the climatological prerequisites and assessing risk by region. **Data needs**: Types of local pests and pathogens and their sensitivity to climatic changes (does the population/occurrence increase); Climatic factors of relevance to the local pests and pathogens, e.g., growing degree days, temperature, drought; Historical cases with locations	**Reference**: Gullino et al. 2022: https://doi.org/10.3390/su141912421 Paini et al. 2016 (agricultural invasive species): https://doi.org/10.1073/pnas.1602205113 IPCC/FAO 2021: https://doi.org/10.4060/cb4769en	

Share of mixed forest of all forests and general tree composition of forests	Mixed forest is more resilient towards changing climatic conditions. Different tree types and varieties have different sensitivity level to climatic changes, also age of trees plays a role. New tree plantations need to account for future potential climate change impacts at the regional level. Climate change can affect the growth and productivity of forests and alter the frequency and intensity of forest disturbances (e.g. insect outbreaks, invasive species, wildfires, storms).	Sensitivity
Simple method: Numerator: total number of timber trees planted in areas likely to be climatically suitable in the long term + Denomiator: total number of timber trees planted in the country Grouping/assessment: by region, by forest type, by different resilience factors (layering) Potential sub-indicators (see references): Share of mixed forests / diversity of tree species Total forest area expansion and afforestation Forest area fragmentation, proportion of natural areas Forest composition (species, age structure)	**Reference**: GIZ/IISD 2014 Santopuoli et al. 2020: https://doi.org/10.1139/cjfr-2020-0166, Linser 2024	
Data needs: Maps, scans or data on forest areas and their composition; data on newly afforested areas and species seeded; Total number of timber trees planted in the country; total number of timber trees planted in areas likely to be climatically suitable in the long term	**Unit:** share (percentage) of mixed , forest, climate resilient tree species, areas of risk	
Limitations: Climate resilient tree species may be associated with trade-offs – e.g. reduced market value, increased sensitivity to pests and diseases, or unexpected, long-term impacts on the ecosystem by introducing alien species into ecosystems. This indicator could be completed with other indicators to assess which tree or combination of tree species is most appropriate under future climatic changes.		

Annual timber losses from pests and pathogens	Changes in temperature and rainfall conditions can lead to changes in pests and pathogens with negative impacts on the timber industry and state of environment.	Sensitivity
Simple method: Enumeration and categorisation. Spatial assessment. **Grouping/assessment:** By region, by forest type, by species **Data needs:** Amount of hectares s of forest lost per year due to pests and pathogens; knowledge on local pests and pathogens and their occurrences	**Reference**: GIZ/IISD 2014, Gullino et al. 2022: https://doi.org/10.3390/su141912421, Davies et al. 2017: https://doi.org/10.1093/forestry/cpaa025	
Potential limitations: Attribution issue: pests and pathogens may be due to a combination of factors (e.g. aging trees, soil erosion, etc.) and not solely temperature and rainfall changes. Estimating risk or future risk could provide more comprehensive understanding to support adaptation, but assessment and computing can be resource-heavy (see references for examples).	**Unit:** hectare/ m^3, economic losses, risk level	

Damages in forests due to weather-related events	Describes the amount, percentage or areal distribution of weather-related damages and assesses the extent of harm inflicted on forest ecosystems resulting from extreme weather phenomena, such as storms, droughts, floods, and wildfires. This indicator is essential for understanding the vulnerability of forested areas to climate change. Certain forest types and species are more susceptible to weather-related damage, e.g., young or aging forests may lack the structural integrity to withstand severe storms, while invasive species can exacerbate the impact of climate stressors.	Sensitivity

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Define the desired damage for indicator: Damage can manifest as tree mortality, reduced growth rates, and loss of biodiversity. Severe weather events can lead to physical destruction of trees, soil erosion, and habitat degradation. Assess the damaged areas or define areas that are more vulnerable. **Data needs**: data on forest damages and causes; data on economic losses or compounding events	**General reference**: Santopuoli et al. 2020: https://doi.org/10.1139/cjfr-2020-0166 van Hensbergen, H. & Cedergren, J. 2020: https://doi.org/10.4060/cb0686en

Amount/cases of weather-related damage to road infrastructure	Describes total number and possible trend, or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions. Certain weather events become more common with changing climate.	Exposure
Data needs: Timing and type of weather events in the target area, Road locations and condition data, data on weather-related damages		General reference: Gössling et al. 2023,

Seasonal distribution and change in interruptions of use in public transport (due to weather)	Describes total number and possible trend or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions (crashes, delays, increased travel time, decreasing road capacity). Understanding the frequency and impact of weather-related disruptions helps policymakers prioritize investments in infrastructure improvements and emergency preparedness.	Exposure
Count the total number of disruptions within the defined time frame. Analysis on trends by comparing data across different years or seasons to identify patterns and estimate changes in such weather events in the context of climate change. **Data needs**: Timing and type of weather events in the target area, data on disruptions in public transport (preferably tagged with cause), public transport usage data for the target area		General reference: Gössling et al. 2023, Leviäkangas et al. 2013, Elyoussoufi et al. 2023: https://doi.org/10.3390/meteorology2040028
Number of weather-related disruptions in traffic and transportation	Describes total number and possible trend or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions (crashes, delays, increased travel time, decreasing road capacity). Understanding the frequency and impact of weather-related disruptions helps policymakers prioritize investments in infrastructure improvements and emergency preparedness.	Exposure
See description above. **Data needs**: Timing and type of weather events in the target area, data on disruptions in traffic and/or transportation (preferably tagged with cause),		General reference: Gössling et al. 2023, Leviäkangas et al. 2013, Elyoussoufi et al. 2023: https://doi.org/10.3390/meteorology2040028

Number of weather-related disruptions in energy or electricity distribution	Number and/or distribution of weather-related disruptions. Can help understand, which weather-related events cause disruptions currently and does the changing climate increase/decrease the risk of occurrence. Extreme weather event can increase in intensity and frequency due to climate change. Understanding the frequency and impact of weather-related disruptions helps policymakers prioritize investments in infrastructure improvements and emergency preparedness.	Sensitivity
Summation, and spatial visualisation, of events grouped by hazard, by area, by disruption type or origin in the energy system. **Data needs**: Information on disruptions in energy systems, power outages, their duration and their causes, number of clients/households affected (without electricity or within the affected area). Information on extreme events. Potential sources: local, disaster risk management agencies, energy companies		
Potential limitations: Focus needs to be determined. A blackout in a major city causes larger damages than in less populated areas. This is not accounted for in the indicator. The indicator could be modifed to include the number of households and companies affected. Furthermore, a single extreme weather event cannot be easily attributed to climate change alone.		**Unit**: number, hours

Mapping of vulnerable populations	Describes social vulnerability in relation to certain hazard (in general, high social vulnerability affects capability to cope in case of most hazards). Social vulnerability to climate change is a multifaceted concept that encompasses various demographic, socio-economic and environmental factors. Recognizing who and where the vulnerable populations are is the starting point to decrease vulnerabilities and increase adaptive capacity. Factors of vulnerability may vary according to the specific climate risk and can be elaborated separately (see data needs).	Adaptive Capacity
Methodology: Selecting hazard or hazards, and populations to be mapped (e.g. based on available data or assessed based on references).		**References on computing:** Social vulnerability to climate change in Helsinki metropolitan area

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Assessment either by 1) spatial assessment of social vulnerability (layers/GIS), or 2) through computing and visualising a social vulnerability index.	(Kazmierczak 2015) (incl. workflow and data processing descriptions) EEA, https://climate-adapt.eea.europa.eu/en/mission/solutions/tools/social-vulnerability-index-svi (language: R)
Data needs: Demographic or other socio-economic data. Social vulnerability can arise from various factors, such as, age structure, income structure, health conditions or disabilities, education level, occupation, gender, ethnicity, unemployment, access to green and blue spaces, access to health services, social isolation, population density etc. Climate data on selected hazard that vulnerability is mirrored to.	
Limitations: List of social vulnerability factors (sub-indicators) are limited by the data availability and should be adjusted locally regarding available demographic data. At a city level, if the information about social vulnerability is to be used to support decision making about targeting resources to different areas, finer-scale information about the variability in social vulnerability to climate change is needed.	**General reference**: ETC/CCA, 2018. (social vulnerability factors, further references)

Development of tools, guides, and policies to support action on climate risks	Appropriate tools can increase the adaptive capacity of relevant governmental and non-governmental bodies and ultimately aid vulnerable stakeholders as well. This indicator could be expanded to track various elements chosen, e.g.: - number of tools, guides, policies developed - number of users of such resources - number of working groups or agencies involved in actions - status of development (production, testing, issued, in use) of tools, guides, or policies	Adaptive Capacity
Limitations: Does not account for quality. Could be completed with additional sub-indicators to assess the quality of these instruments, to what extent these instruments are being scaled up and their impacts on climate adaptation.		**General reference**: GIZ/IISD 2013, EEA 2023

Capacity building and awareness raising actions	This indicator aims to describe and monitor action that increase adaptive capacity in the community. Can be expanded to include the chosen elements, e.g.: - Number of staff or other target groups having received training on climate adaptation - Number of trainings or campaigns conducted - Number of stakeholders using and distributing climate information and/or number of local active volunteers in climate-risk-related fields	Adaptive Capacity, Monitoring
Methodology: The target group, theme or sector of the action to be defined as well as which kind of actions are taken (categorization). Summation of selected actions and categories that can be assessed by type of actions, by goals of actions met, by district/region, by sector.		**Source**: GIZ/IISD 2013, EEA 2023
Data needs: Data/information on local capacity building and awareness raising actions that are related to climate change adaptation or disaster risk reduction.		**Unit:** Number (of actions, events, participants) or more qualitative mesurement unit

Number of financial mechanisms identified to support climate change adaptation	Incentives and/or funding can be prerequisites for climate-adaptation work. Climate adaptation will require additional money; funding can be mobilized in various ways - e.g. tax contributions from activities which generate greenhouse gases, levies on activities or people settling in high risk areas.	Adaptive Capacity
Sum of identified financial mechanisms and/or sum of financing potentially available through these mechanisms. Could provide an estimate (ranking) on the potential. **Assessment:** by region, by target sector, by livelihoods		**Source/reference:** GIZ/IISD 2014, EEA 2023
Data needs: Number of climate adaptation financial mechanisms in the country, number of identified financial mechanisms locally relevant, data on existing adaptation/mitigation financing and future needs		**Unit**: number (sum)
Limitations: This indicator provides information on the existence of financial mechanisms but not on which ones are most appropriate, if they are sufficient and easily accessible. The indicator needs goals (what is aimed at with the financing) in order to aid strategic decision making.		

Funding for climate-adapted construction and renovation	Climate-adapted construction and renovation can prevent or minimise damage resulting from higher temperatures or extreme climatic events and can contribute to climate protection, e.g. through energy savings, additional cooling of spaces. Incentives and/or	Adaptive Capacity

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	funding can be prerequisites for people or businesses to undertake climate-adapted construction work.	
Summation and categorisation of funding based on their targets. Assessment by district/region, by construction vs renovation, by sector receiving funding.		**Source/reference: Reference**: GIZ/IISD 2014, EEA 2023
Data needs: Data on provision of funds, information on locally selected action for climate-resilient construction and renovation & what the goals are (protect from indoor heat, save energy).		**Unit:** € or other currency, number of projects or finished buildings/renovations
Limitations: Without any further regulations/stipulations and assessment it is not self-evident that funds are effectively used for construction which is really climate-adapted. It is not clear whether the funds target the most vulnerable areas, properties or people. Funds for renovation need not necessarily be spent on work that enhances adaptation.		

Percentage of transport infrastructure standards revised to consider climate risks	Transport infrastructure has a long lifespan: it is important that technical standards respond to current and future potential impacts of climate change. A review and adaptation of technical standards for transport networks (infrastructures and equipment) is therefore needed to support climate adaptation in this sector.	Adaptive Capacity
Numerator = total number of revised standards for transports networks that are vulnerable to climate + Denominator = total number of standards for transport networks vulnerable to climate change Assessment: By mode of transport, by region; percentage of reference standards identified which are vulnerable and where changes are proposed; percentage of reference standards which have actually been modified		**General reference**: GIZ/IISD, 2014
Data needs: Information on relevant authorities or stakeholders; Total number of standards for transport networks vulnerable to climate change; total number of revised standards for transports networks that are vulnerable to climate change		**Unit**: %
Potential limitations: This indicator does not capture the quality of the revised standards, if they have been implemented or their effectiveness.		

Number of properties with retrofitted resilience measures	Property designs need to account for extreme weather events (e.g. floods) and changes in water availability and temperature due to climate change. These measures could include: flood resilience, water meters, water efficicency, cooling, etc.	Adaptive Capacity
Summation and spatial assessment by GIS. Assessment by district/region, by measure.		**General reference**: GIZ/IISD, 2014
Data needs: Number of properties, number of measures taken, To further specifiy the data needs, the specific resilience measures to be tracked must be defined		**Unit**: Number
Limitations: This indicator could also be combined with other indicators to assess the quality or effectiveness of retrofitting measures on climate risk management and the extent to which the properties are actually exposed to flood, higher temperatures, etc. now and in the future.		

Uptake of early warning and disaster preparedness systems	This indicator could include the chosen elements, e.g. systems for: air or water quality, flood or fire protection, heatwaves or cold spells.Early warning systems can help people and businesses prepare for and minimize the negative impacts of climate hazards on their activities.	Adaptive Capacity
Summation and/or spatial assessment (GIS) of regional/areal differences. **Assessment:** By types of early warning systems, by region, by hazard types, by target groups.		**General reference:** GIZ/IISD, 2014 / UK Adaptation monitoring and Evaluation framework (2013)
Data needs: Number of early warning systems and/or rescue services/authorities/population using these systems.		**Unit:** number, % of target group/population
Limitations: This indicator could be completed with other indicators to assess the effectiveness of early warning systems. The indicator does not consider whether contingency plans are in place. In addition, air and water quality deterioration may be due to other factors than climatic changes.		

4.2 Limitations in computing and using indicators

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The scope of VALORADA has inherent benefits to computing indicators, such as synergies between demonstrator regions and community of practice created in the project, as well as synergies between other EU projects (e.g., CLIMAAX). However, some common challenges/limitations were also identified:

Data access and appropriate quality

1. Missing relevant data, especially non-climate data

There are comprehensive and spatially gridded time series of datasets to characterise climatic impact drivers (climate variables) in European context. However, there are far more challenges with acquiring data to describe non-climatic impact drivers (non-climate variables) and yet this kind of data is crucial to describe exposure, vulnerability or adaptive capacity of a locale. (EEA 2024a) The accuracy and reliability of indicators depend heavily on the quality and availability of data and inconsistent or incomplete data can lead to misleading indicators (IPCC 2020).

In addition to local non-climate data, which is much needed, some European sources can assist. Examples are the European Commission DRMKC RIsk Data Hub (website) that provide standardized European data on, e.g., exposure, vulnerability (composite vulnerability index) or disaster losses (estimations of affected population or economic losses). Also, CLIMAAX D2.3 (pdf-file) provides a recent overview of European vulnerability and exposure projections and information on identified datasets.

2. Difficulties to get data into desired format

Different analysis tools, based on Python, R or GIS-based systems, operate on slightly different data formats. Adopting standards to handle data and metadata across project ensures compatibility and ease of integration. Also, data transformation tools can aid in this. Using either existing tools (ETL tools) that convert data from one format to another or develop custom in programming languages like Python or R to automate data formatting tasks, ensuring consistency and efficiency.

3. Quality assurance and selecting appropriate data (especially climate model data)

As highlighted in VALORADA Deliverable 4.3, any climate scenario based on a regional climate model (RCM) is highly dependent on the global climate model (GCM) driving it. To comprehensively capture the range of potential outcomes and related uncertainties specific to various RCMs and GCMs, it is essential to assess an ensemble of simulations that combines different RCMs with various GCMs. In selecting feasible GCM-RCM pairs from the EURO-CORDEX data, it is crucial to evaluate the performance of the downscaled data by comparing historical simulation outputs with observed climate statistics. Accordingly, VALORADA Deliverable 4.3 outlines one of the goals of VALORADA Task 4.2 as providing guidelines for model selection.

Computing and visualising indicators

4. Interoperability of workflows

Different coding languages in reference sources or existing workflows (Python, R, C in some GIS workflows) and interoperability of datasets. Plugins that translate between coding languages, such as from Python to GIS, might provide a solution. Requires cooperation with project partners (ECMWF) and other projects (CLIMAAX) to get access to plugins.

5. Output of the indicators

Identification and communication of uncertainties are vital. Climate systems are complex and inherently uncertain, which is inseparable part of climate change, its impacts or adaptation to it and certainly also part of climate projections. Uncertainty does not render usefulness of the information provided, when appropriately communicated.

On complexity: Indicators might oversimplify the complexities of both climate system and non-climate factors, potentially leading to inadequate or inappropriate policy responses (IPCC 2020). Essential to ensure during the process, what indicators describe, what is their goal/aim and what are its limitations.

6. Issues in using indicators

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See chapter 3.1 on allocation criteria, which aims to help avoiding issues and limitations in the use of indicators. Main points are to ensure local validity and realism in goal setting & continuity. Institutional use of indicators and roles that indicators take in local decision-making take time to form. In addition, challenges related to issues in data and data management and gaps identified in demonstrator regions are described in detail in VALORADA deliverables *D2.2 Characterisation of the Data Value Chain in each Demonstrator* and *D1.2 Gap analyses for each demonstrator.*

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6. Annexes

Annex 1. Hazard indicators

Annex 2. Indicators of exposure, sensitivity and adaptive capacity

Annex 3. Indicators brainstormed in workshops (2023)

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ANNEX 1. Hazard indicators here are mainly described by climatic impact drivers, such as weather and climate variables or indexes. Overview of the available indices in the European Climate Data Explorer here, and indices or datasets provided by Climate Data Store available here.

Indicator (Index or variable)		Description	Category
Temperature	Mean temperature	Change in annual/monthly temperature	Hazard
	Heatwaves, Consecutive hot days, Number of hot days		Hazard
	Maximum temperature, Minimum temperature		Hazard
	Number of frost days		Hazard
	Growing degree days		Hazard
	Heating degree days, Cooling degree days		Hazard
	Tropical nights, High Universal Thermal Climate Index (UTCI) days		Hazard
Precipitation	Mean precipitation, Snowfall amount	Change in annual seasonal/monthly precipitation	Hazard
	Extreme precipitation days, Extreme precipitation total, Maximum consecutive 5-day precipitation		Hazard
Drought/Aridity	Consecutive dry days, Meteorological drought duration and/or magnitude, The Aridity Actual index		Hazard
	Mean Soil moisture		Hazard
	(Bare soil) Evaporation, Transpiration		Hazard
	Fire weather index, Days with high fire danger		Hazard
Wind	Mean wind speed, Extreme wind speed days		Hazard
Coastal/Oceanic	Relative sea level rise, Extreme sea level rise		Hazard
	Sea surface temperature, Marine heatwaves		Hazard

ANNEX 2. Simple table with name, description and category (exposure, sensitivity, adaptive capacity)

Indicator Name	Description	Category
Number of households affected by drought	Drought impacts households, e.g., through water shortages, restrictions in water use or dependence on alternative water sources (e.g. the number of days per year with water use regulation on certain areas, number of households there). It can affect food security or cause economic strain increased costs (water, electricity). Indicator can also just describe the number of households in a high risk area.	Exposure
Number of livestock affected by drought	Number of livestock or livestock-related livelihoods located in high drougt risk areas. Could also consider impacts to livestock, such as changes in water and fodder availability, loss in livestock productivity, reduced weight, increased health issues due to drought.	Exposure
Number of people at high risk of heat stress	Describes risk areas for heat stress and the number of population residing there. Provides better understanding if additional risk factors (vulnerability) such as old or very young age, chronic health conditions, low income, low level of education etc. among population considered.	Exposure, Sensitivity
Number of people living in flood-prone areas	A high number of people living in flood prone areas shows a high exposure to flood risks. Could be completed with other indicators to assess the impacts of floods on people living in flood prone areas (in terms of socio-economic impacts).	Exposure
Number of properties flooded per year	Climate change increases the frequency and intensity of extreme weather events such as floods. It can also change the location and timing of floods.	Exposure
Number of businesses located in areas of flood/coastal erosion risk	Smaller number of businesses located in areas of flood/coastal erosion risk shows a reduced exposure of businesses to those risks. This includes also number/locations of industries vulnerable to flooding (that can cause a further threat, e.g., of chemical dispersion).	Exposure
Number of hospitals located in areas at risk from flooding/coastal erosion	Essential services, such as hospitals should be located outside of risk areas to prevent them from being damaged and/or destroyed from floods/coastal erosion. Could be completed with other indicators to assess the vulnerability (i.e. sensitivity and adaptive capacity) or by including other facilities typically residing vulnerable populations (e.g. nursing homes, kindergardens, schools)	Exposure
Number of critical infrastructures in areas at risk from flooding	Essential services, such as hospitals should be located outside of risk areas to prevent them from being damaged and/or destroyed from floods/coastal erosion. Could be completed with other indicators to assess the vulnerability (i.e. sensitivity and adaptive capacity)	Exposure

Share of flood risk area in the city or region	Describes the location and/or share of flood risk areas within city or region.	Exposure
Number of households within most deprived communities located in areas of flood/coastal erosion risk	This indicator assesses the exposure of households within most deprived communities to flood/coastal erosion risk. It could be completed with other indicators to assess the vulnerability (i.e. sensitivity and adaptive capacity) of the households to flood/coastal erosion risk.	Exposure
Change in occurrence of water- and food-borne diseases		Exposure
Change in occurrence of vector-borne diseases	Climate change increases the areal distribution and probability of occurrence of many vector-borne diseases (carried by, e.g., ticks and mosquitos)	Exposure
Change in climatic preconditions for vector-borne diseases	Climate change increases the areal distribution and probability of occurrence of many vector-borne diseases (carried by vectors such as ticks and mosquitos)	Exposure
Number of people permanently displaced from homes because of flood, drought, or sea-level rise		Exposure
Location of abandoned lands	Abandoned or mal-maintained land areas pose an increased wildfire risk.	Exposure
Seasonal distribution and change in interruptions of use in public transport (due to weather)	Describes total number and possible trend, or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions. Certain weather events become more common with changing climate.	Exposure
Amount/cases of weather-related damage to road infrastructure	Describes total number and possible trend, or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions. Certain weather events become more common with changing climate.	Exposure
Number of weather-related disruptions in electricity supply	Describes total number and possible trend, or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions. Certain weather events become more common with changing climate.	Exposure
Number of weather-related disruptions in traffic and transportation	Describes total number and possible trend, or can be combined with (even rough) location information. Extreme weather events, such as heavy rainfall, heatwaves or storms, can cause damage and disruptions. Certain weather events become more common with changing climate.	Exposure
Urban Heat Island Effect	Climate change affects the urban climate in a way that can result in severe thermal stress with effects on people's health (well-being, mortality, morbidity). The Manifestation and magnitude of the heat island effect is not only due to changing climatic parameters but also influenced	Exposure

	by architecture, building density and materials, urban planning and green spaces etc.	
Distribution of (climate-sensitive) species	Climate change can shift the geographic ranges of some species and alter biodiversity. Vanishing or decreasing number of climate sensitive species indicates ongoing change in ecosystem.	Exposure, Sensitivity
Distribution shifts of plant and animal species	Climate change could shift the geographic ranges of some species and alter biodiversity.	Exposure
Reduced work productivity due to heat stress	Reduced work productivity due to heat stress Increased warming and humidity can lead to reduced work productivity especially for outdoor activities.	Sensitivity
Changes in human thermal comfort in urban environments	Urban thermal comfort is a critical aspect of city livability, influenced by complex interactions between the built environment and meteorological factors. Urban design strategies, such as implementing cool materials and urban greenery, can impact thermal comfort	Sensitivity
Deterioration of well-being due to non-adapted buildings		Sensitivity
Increase in the number of pathogens in coastal waters		Sensitivity
Losses of GDP in percentage per year due to extreme events	Extreme precipitation can damage the economic infrastructure and value chains and cause losses in GDP (Locally this could be measured in another unit than GDP). The indicator gives an indication as to the level of vulnerability of different sectors to extreme weather.	Sensitivity
Financial losses to businesses due to extreme weather events	Climate change can impact businesses negatively through the destruction of infrastructure and disruptions along their supply chains. For example: costs of damages or delays caused.	Sensitivity
Disruptions to economy/livelihoods due to water scarcity, wildfire, or flooding	Could describe the losses, number of disruptions to certain professions/sectors, number of professions (and people working in them) vulnerable to or been affected by water scarcity, wildfires, or flooding. Requires information of locally relevant professions/livelihoods that are affected.	Sensitivity
Flood-related disturbances to agricultural livelihoods	Refers to the disruptions and challenges to agricultural sector due to floods. These disturbances can be, e.g., crop failure (submerge, root damage and rot), loss in yield and seedlings, rising costs and economic strain, soil degradation, delayed planting and harvesting.	Sensitivity
Drought-related disturbances to agricultural livelihoods	Refers to the disruptions and challenges to agricultural sector due to prolonged periods of low rainfall or water shortages. These disturbances can be, e.g., crop failure (especially "cash crops" that farmers rely on for livelihood), reduced yield, loss of seedlings, rising costs. Could also be measured in loss of income, increase in debt or unemployment.	Sensitivity

Percentage of total livestock killed by drought	Describes the loss of livestock due to drought or related environmental conditions.	Sensitivity
Shifts in urban energy demand (e.g., due to increased need for cooling)		Sensitivity
Total length of sewerage and drainage network at risk from climate hazards	A sewerage and drainage network may be vulnerable not only because of its location in a hazardprone area but also its condition (this indicator focuses on the former). Inadequate preparation may mean flooding, water shortages, water quality issues, etc. as a result of climate hazards.	Sensitivity, Exposure?
Number of disruptions in energy system due to heat and drought	Number and/or distribution of weather-related disruptions. Can help understand, which weather-related events cause disruptions currently and does the changing climate increase/decrease the risk of occurrence.	Sensitivity
Number of disruptions in energy system due to flooding	Number and/or distribution of weather-related disruptions. Can help understand, which weather-related events cause disruptions currently and does the changing climate increase/decrease the risk of occurrence.	Sensitivity
Number of weather-related disruptions in energy or electricity distribution	Number and/or distribution of weather-related disruptions. Can help understand, which weather-related events cause disruptions currently and does the changing climate increase/decrease the risk of occurrence.	Sensitivity
Disturbances in food production or import affecting food security	Number and/or distribution of weather-related disruptions. Can help understand, which weather-related events cause disruptions currently and does the changing climate increase/decrease the risk of occurrence.	Sensitivity
Disruptions to population due to water scarcity	Describing, for example, the number of days per year with water use regulation	Sensitivity
Number of days with poor air quality due to wildfires	Poor air quality worsens the effects of heat on people's health.	Sensitivity
Remoteness of areas vulnerable to wildfires		Exposure
Increase in soil degradation and desertification	Describes either future risk based on climate projections and possibly land use. And/or combines projections with local information on high-risk areas of soil degradation, increased erosion (including agricultural lands) and desertification due to, e.g., their current state, type of vegetation, activities such as agriculture or changes in land use.	Sensitivity
Changes in biodiversity (e.g., populations of birds and butterflies) around agricultural lands	Monitoring locally relevant species, for example birds and butterflies, that are sensitive to environmental change. For example, butterflies are sensitive to environmental change and a good indicator of the health of the environment. Currently their numbers are declining in many areas of Europe (Source: EEA).	Sensitivity
Water usage rate in agriculture	Important indicator in understanding water needs and need for more efficient practices.	Sensitivity
Number of hectares of productive land lost to soil erosion		Sensitivity

Share/percentage of agricultural crops vulnerable to climatic changes	Changing crops to more resilient ones can increase resilience of agricultural sector and food security.	Sensitivity
Share of mixed forest of all forests and general tree composition of forests	Mixed forest is more resilient towards changing climatic conditions. Different tree types and varieties have different sensitivity level to climatic changes, also age of trees plays a role. New tree plantations need to account for future potential climate change impacts at the regional level.	Sensitivity
Change in the threat of pests and diseases harming agriculture/forestry	Changing climate is expected to significantly impact agricultural insect pests in Europe by making the climatic preconditions more suitable for certain pests to reproduce and diseases to spread. Vulnerable forests can be prone to diseases in changing climate. Rising temperatures are likely to cause poleward range shifts and increase in the number of generations for many pest species, and to increase prevalence and severity of crop pathogens and fungal infections in some crops. Also new invasive pests and diseases might arrive to Europe.	Sensitivity
Annual timber losses from pests and pathogens	Changes in temperature and rainfall conditions can lead to changes in pests and pathogens with negative impacts on the timber industry and state of environment.	Sensitivity
Damages in forests due to weather-related events	Describes the amount, percentage or areal distribution of weather-related damages.	Sensitivity
Combustible biomass in the forests (risk during dry periods)		Sensitivity
Number of surface water areas subject to declining water quality due to extreme temperatures	Extreme temperatures in the context of climate change can lead to water quality degradation. Vulnerability maps can help identify hot-spots and support decision-making.	Sensitivity
Total forest area impacted by wildfire per year	Increasing temperature due to climate change can lead to increase wildfire with negative impactson forest resources, local populations and tourism.	Sensitivity
Mapping of vulnerable populations	Describes social vulnerability in relation to certain hazard (in general, high social vulnerability affects capability to cope in case of most hazards). Recognizing who and where the vulnerable populations are is the starting point to decrease vulnerabilities and increase adaptive capacity. Factors of vulnerability may vary according to the specific climate risk and can be elaborated separately (see data needs). Can be presented as hotspots, maps, risk indexes.	Adaptive Capacity
Development of tools, guides, and policies to support action on climate risks	This indicator could be expanded to track various elements chosen, e.g.: - number of tools, guides, policies developed - number of users of such resources - number of working groups or agencies involved in actions	Adaptive Capacity

	- status of development (production, testing, issued, in use) of tools, guides, or policies - etc.	
Capacity building and awareness raising actions	This indicator can be expanded to include the chosen elements, e.g.: - Number of staff or other target groups having received training on climate adaptation - Number of trainings or campaigns conducted - Number of stakeholders using and distributing climate information and/or number of local active volunteers in climate-risk-related fields	Adaptive Capacity, Monitoring
Number of financial mechanisms identified to support climate change adaptation	Incentives and/or funding can be prerequisites for climate-adaptation work.	Adaptive Capacity, Monitoring
Number of businesses with risk management plans considering climate change aspects or adaptation options		Adaptive Capacity
Percentage of farmers and fisherfolk with access to financial services		Adaptive Capacity
Funding for climate-adapted construction and refurbishment	Climate-adapted construction and refurbishment can prevent or minimise damage resulting from higher temperatures or extreme climatic events and can contribute to climate protection, e.g. via energy savings. Incentives and/or funding can be prerequisites for people or businesses to undertake climate-adapted construction work.	Adaptive Capacity
Total sum of investments in programs for livestock protection	Livestock is an important source of livelihood and income. Investing in adaptation measures increase the farmers' adaptive capacity can offset the negative repercussions of climate change.	Adaptive Capacity
Percentage of hydroelectric projects that consider future climate risks		Adaptive Capacity
Percentage of transport infrastructure standards revised to consider climate risks		Adaptive Capacity
Number of properties with retrofitted resilience measures	These measures could include: flood resilience, water meters, water efficicency, cooling, etc.	Adaptive Capacity
Uptake of early warning and disaster preparedness systems	This indicator could include the chosen elements, e.g. systems for: - air or water quality - soil and land degradation - flood or fire protection - etc.	Adaptive Capacity
Number and area of green spaces in urban environments	Could also be adopted as area of green space per citizen, ratio of green spaces in different urban environments or areas or expanded to include connectivity of greenspaces.	Exposure

Share of permeable surfaces in urban environments	Describes the share of permeable surfaces in urban environment, related to risk of pluvial flooding. Can also be related to human comfort during heat.	Exposure
Percentage of coastline under marine protection		Adaptive Capacity
Compliance with fishing quota		Adaptive Capacity

ANNEX 3. Indicators brainstormed in workshops (2023).

The indicators suggested during the contextualization workshops in the Autumn 2023.

Demonstrator region: Czech Republic

Climate parameters (hazard)	**Climate impacts (exposure and vulnerability) (Information about the observed impacts of climate variability and change on socio-ecological systems)**	**Adaptation action (implementation): (Information to help track the implementation of adaptation strategies)**	**Adaptation results (outcome): (Information to help monitor and evaluate the outcomes of adaptation strategies)**
	• The number of traffic accidents resulting from the temperature • The number of treated populations • The changes in surface moisture • The changes on the water table • The changes in the height of the river level • The number of days per year the land is sown • The costs of replacement water supply • The number of days per year with water use regulation • The area of roofs from which precipitation is accumulated/total roof area	• Assessing the appropriateness of tree species composition • Assessing the appropriateness of the trees' age distribution • Assessing the percentage of land under cultivation • Monitoring of irrigation at measuring points • Monitoring of Insect population • Monitoring of water consumption trend (cubic meter/month/organization or employee) • Increasing the number of air-conditioned public transport cars • Increasing the number of permeable surfaces • Defining time limits for emergency vehicles • Conducting biomonitoring	• Number of new emergency vehicles per year • Use/occupancy of public transport • Amount of built-up area to permeable area • Amount of retained water resulting from adaptation actions • The relationship between water storage, water consumption, and overall water balance

Demonstrator region: France, Occitanie

Climate parameters (hazard)	Climate impacts (exposure and vulnerability)	Adaptation action (implementation)	Adaptation results (outcome)
	• Economic losses due to delayed intervention • Extent of land susceptible to heat stress • Soil type, agro-potential, and biochemical composition • Number of productive days lost due to illness • Change in productivity levels • Percentage change in agricultural income • Trends in the number of workplaces • Impact on food security • Reduction in agricultural land area • Dependence on import/export for territorial sustenance	• Proportion of outdoor breeding, building types, or production methods (e.g., local, organic). • Crop rotation practices. • Engagement and utilization of professional networks. • Profile and demographics of farmers. • Investment per hectare of land. • Changes in agricultural cultures and practices.	• Reduction in random losses and damage. • Number of young farmers entering the industry. • Size of crop farms (e.g., average farm size). • Number of members in agricultural cooperatives.

Demonstrator region: Central Greece

Climate parameters (hazard)	Climate impacts (exposure and vulnerability)	Adaptation action (implementation)	Adaptation results (outcome)
	• Number of professions affected by wildfires. • Number of tourism activities in vulnerable areas. • Forest density	• Accessibility to remote areas for emergency response. • Number and type of educational institutions focused on climate resilience. • Responsibilities and coordination among different stakeholders. • Volunteer activities related to climate adaptation and disaster response. • Population demographics, with a focus on vulnerable groups (e.g., children, elderly).	• Availability of water to be used for firefighting • Population of protected flora and fauna

Demonstrator region: Bulgaria

Climate parameters (hazard)	Climate impacts (exposure and vulnerability)	Adaptation action (implementation)	Adaptation results (outcome)
• Dynamics in temperature amplitudes across different urban zones. • Number of days with extremely high temperatures.	• Urban zones affected by climate impacts (categorized using digital data) • Number of fire incidents • Percentage of days experiencing drought • Costs associated with street water cleaning due to climate effects • Trends in the percentage of green spaces within urban areas • Ratio of soil to impervious surfaces • Percentage of areas vulnerable to the canyon effect • Number of climate-related complaints • Number of emergency calls related to climate events • Number of people requiring emergency services due to temperature-related health issues • Extent of deforestation • Soil permeability levels • Groundwater levels • River water levels • Extent of flooded areas • Impact on livestock and crop production	• Implement statistical health monitoring for general and specific social groups. • Develop and update population statistics and tourist data for better resource planning. • Ensure the availability and use of air quality data for public health and policy measures. • Maintain a digital register of green canopy by tree species for urban greening efforts. • Monitor and increase the percentage of green areas based on urban zone types. • Assess and manage the percentage of densely built-up areas to improve resilience. • Evaluate and standardize building types and materials for climate adaptation. • Establish and maintain a network of monitoring points in neighboring municipalities. • Enhance the frequency and effectiveness of cleaning and preventive measures at the regional level. • Increase the number of institutions responsible for effective water management. • Track the year of construction or last repair of hydrotechnical facilities to plan upgrades. • Assess population distribution based on socio-economic status for targeted adaptation strategies. • Monitor daily, monthly, and yearly electricity consumption to improve energy efficiency. • Use biodiversity indices to guide onservation and adaptation actions. • Utilize historical data on flooded areas to inform future flood risk management strategies. • Incorporate data from the Main Directorate for Civil Registration and Administrative Services in adaptation planning.	• Number of types of species in the green system • number (%) of energy-efficient buildings

Demonstrator region: Molise, Italy

Climate parameters (hazard)	Climate impacts (exposure and vulnerability)	Adaptation action (implementation):	Adaptation results (outcome)
	• Number of companies at risk • Geographic locations at risk • Habitats of community interest at risk • Total land area impacted by climate-related incidents. • Farm profitability, change in income compared to the previous year, reflecting the economic impact on agriculture. • Number of residents relocating from affected areas. • Count of essential facilities (schools, hospitals, nursing homes, etc.) within hazard zones. • Number of individuals residing in areas exposed to hazards.	• Measuring the degree of slope to assess terrain stability. • Area of vegetation along rivers, measured in hectares, to evaluate riparian health. • Analysis of soil types and substrates in the region. • Funds allocated for the upkeep of road infrastructure. • Assessment of different road types to determine municipal isolation levels.	