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UKRAINIAN CLIMATE OFFICE

Manual for the city's climate risk assessment

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Background

At the recent UN Climate Conference (COP29) in Baku, investors raised critical concerns about the design of climate adaptation plans. Key messages included:

- «Your Adaptation Plan does not provide an understanding of, or means of underwriting, climate risks.»
- «We have the financing, but the projects are not well designed and are not based on shared understanding of risk and climate data.»
- «We are not sure that Readiness processes are having the impact that they should be.»

These concerns reflect a broader challenge faced by many countries: a lack of clear, risk-based adaptation planning.

This gap is especially visible in Ukraine, where climate change adaptation is not yet included in the country's Nationally Determined Contribution (NDC) under the Paris Agreement.

To support Ukrainian municipalities in addressing this challenge, the Ukrainian Climate Office project developed this manual to guide climate risk assessments and help integrate adaptation into local planning processes.

Acknowledgements and Methodological Background

This manual builds on methodologies and insights developed and tested in various international and national projects, including:

- The Lithuanian project «Preparation of climate change forecasts, a national study on the sensitivity and vulnerability of Lithuanian municipalities to climate change, and a climate change adaptation plan for the most sensitive municipality» implemented by «Estonian, Latvian & Lithuanian Environment»[1].
- The project Formulating and Evaluating Water Resources Adaptation Options to Climate Change Uncertainty in the Carpathian Region, (CRDF Project No. UKG2-2971-KV-09) implemented by IMMSP and the Institute for Water Resources, US Army Corps of Engineers (DOI:10.13140/2.1.2674.1124).
- The EU-funded project EAST AVERT (2013–2017), focused on flood monitoring in the upper Siret and Prut River basins.
- Project No. 28/01/0421 of the National Research Foundation of Ukraine (2020–2021), aimed at predicting hazardous impacts of flood and contamination in the Dnipro River.
- The UNDP-UKR-00314 project «Indicators of climate change impacts and responses for socio-economic sectors and natural components in Ukraine».

1. https://environment.lv/en

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Abbreviations

A Adaptive Capacity. The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

CC Climate change.

CCI Climate change impact. The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability.

CID Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.

D Driver.

E Exposure is the presence in the studied area of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

I Impacts.

L Likelihood, determined by the probability of hazard which may affect population and assets.

P Pressure.

R Risk. The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change (IPCC). Risk is «The effect of uncertainty on objectives» whereas risk management is «coordinated activities to direct and control and organization with regard to risk» (ISO 31000).

Re Response.

Rs Resilience. The capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure.

St State/Index of Climatic Impact Driver.

S Sensitivity.

V Vulnerability is the characteristic of population or asset in the area making it particularly susceptible to damaging effects of climate change (e.g., the fragility of constructions).

Introduction

A climate risk assessment is a structured process to identify, evaluate, and manage the risks linked to climate change. It examines how climate-related hazards may impact people, the economy, and ecosystems. These assessments help national and local governments develop strategies and measures to reduce vulnerability and protect communities, infrastructure, and livelihoods.

In Ukraine, climate risk assessments are especially relevant in light of the country's commitments under the Paris Agreement, which aim to:

1. Limit global temperature rise through mitigation, and

2. Strengthen the resilience of social, economic, and environmental systems through adaptation.

The IPCC's Sixth Assessment Report (AR6) underlines that neither mitigation nor adaptation alone is sufficient. To ensure sustainable development, both must be pursued together through what the IPCC calls climate-resilient development, a pathway that integrates emissions reductions and adaptive capacity while promoting social fairness and respecting natural systems.

AR6 also stresses that effective adaptation requires more than short-term responses. It calls for systemic transitions in energy, ecosystems, infrastructure, and society, drawing on diverse sources of knowledge, including local and Indigenous expertise.

Key messages for policymakers include:

- Current development paths, combined with the observed effects of climate change, lead away from sustainable development rather than toward it.

- Only simultaneous emissions reductions and adaptation can ensure sustainable development for all.

- The opportunity for climate-resilient development is closing rapidly.

This requires a shift in how we understand security → not as the absence of risk, but as the ability to manage and reduce it. A risk-based approach, as promoted by the OECD, helps decision-makers prioritise actions by weighing the likelihood and impact of climate risks against the costs and benefits of response. This supports smarter planning and more targeted investment in resilience.

Definitions

While the development of Ukraine's Adaptation Strategy involved constructive discussions and reflected recommendations from the IPCC AR6, some aspects of the recently adopted Law *«On the Basic Principles of State Climate Policy»* would benefit from greater alignment with international terminology and understanding. In particular:

The phrase «mitigation of the consequences of climate change» appears to conflate mitigation with adaptation. In international usage, «mitigation» refers specifically to reducing anthropogenic greenhouse gas emissions.

«Reducing the negative effects of climate change» can be achieved not only through mitigation but also through effective adaptation measures.

Terms like «achieving climate neutrality» and «building resilience» describe means or actions rather than final objectives. These contribute to the overarching goal set by SDG 13: «Take urgent action to combat climate change and its impacts.»

It is important to note that while mitigation delivers long-term benefits by reducing the intensity of climate change, adaptation can reduce risks immediately — for example, relocating people from flood-prone areas instantly lowers the risk of harm.

Clarifying these distinctions could strengthen coherence across national climate policies and enhance Ukraine's alignment with global best practices.

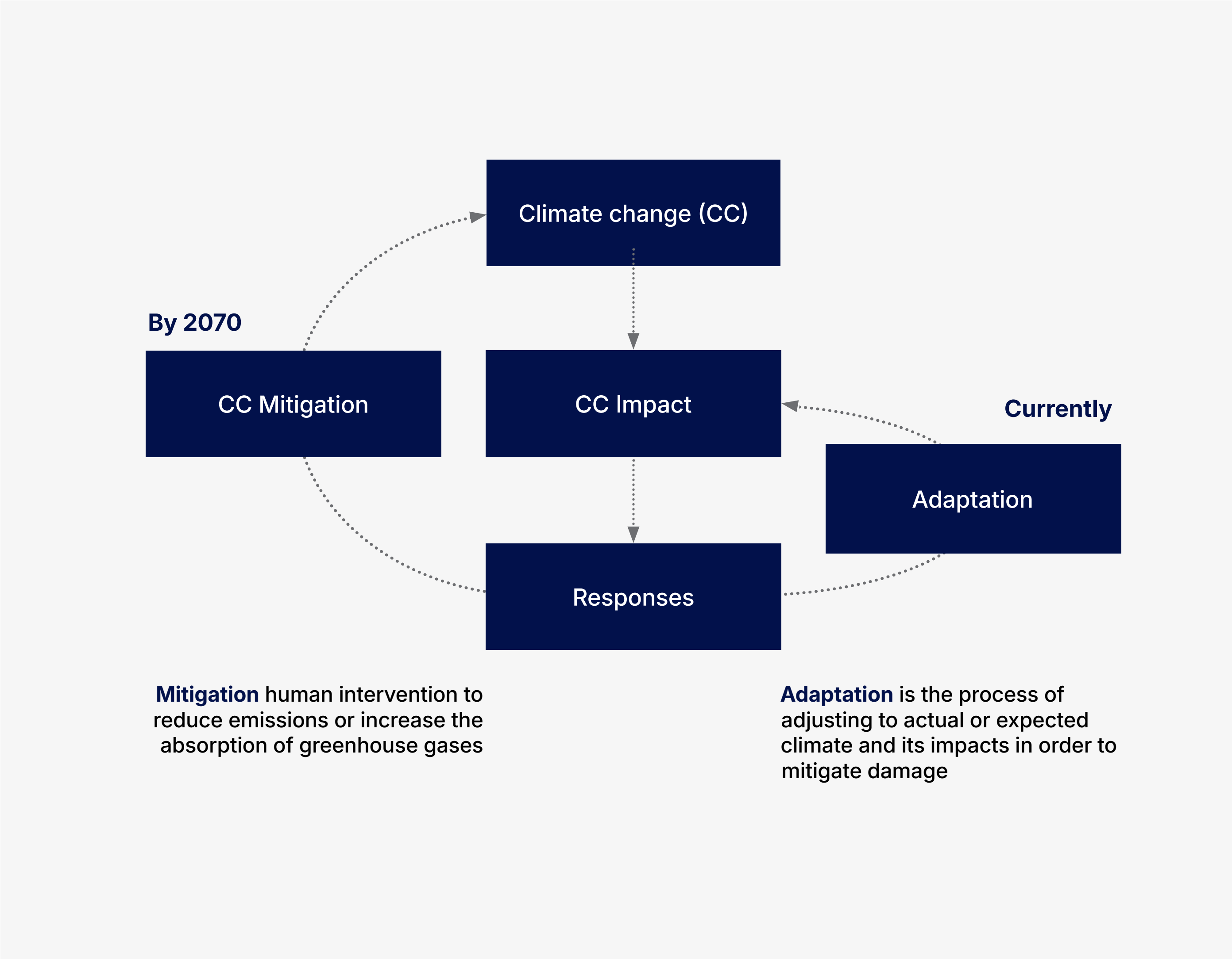

Figure 1. *Interaction of climate change, mitigation and adaptation. (Source: Figure by author).*

Steps in climate change risk assessment

This manual is based on the practical experience and methodology developed in Lithuania, which has been adapted to the Ukrainian context to guide local policymakers in assessing and managing climate risks.

Below we explain how the methodology used in Lithuania has been applied to assess climate risks at the municipal level.

The following diagram shows the main stages of climate change risk assessment.

Step 1.

Building impact chains: Climate Impact Drivers (Indices) ⟶ Climate Change Impacts

Step 2.

Selection of Climate Change Impacts for further analysis: Qualitative Assessment of Exposure and Vulnerability to CC Hazards

Step 3.

Assessment of Exposure and Vulnerability to CC Hazards

Step 4.

Selection of Climate Change Impacts for Comprehensive Response Development

Step 5.

Mapping of climate risks

Step 1.

Building Climate Impact Chains: From Climatic Impact Drivers (and their Indices) to Climate Change Impacts

Climate impact chains show how specific climate factors, such as temperature increases or extreme rainfall, lead to direct or indirect impacts on both natural and human systems (e.g. ecosystems, agriculture, transport, or health). These chains help to:

- Identify and organise climate-related risks,
- Assess exposure, vulnerability, and overall risk, and
- Communicate risks clearly to local stakeholders.

Impact chains also support the evaluation of key variables (climate impact indicators) and how different sectors are interconnected.

Selecting Drivers and Indices

This manual based on guidance from IPCC Working Group I and the European Environment Agency (EEA Report No. 1/2017), the project team identified eight categories of climate drivers (referred to as «D types»), each associated with a range of measurable indicators («D indices»).

Considering the availability of meteorological information, the project team settled on the following list of sectors, drivers, and their indices for further selection of the most significant drivers and impacts:

Table 1:
List of sectors, drivers, and their indices for further selection of the most significant drivers

Selected economic sectors	Climatic Impact Driver, D	Selected D Indices, S
1. Public health **2.** Agriculture **2.1.** Farming **2.2.** Livestock **3.** Biodiversity **3.1.** 3.1. Protected areas **3.2.** Forest ecosystems **4.** Water resources **4.1.** Water resources management **4.2.** Floods **4.3.** Coastal areas **5.** Infrastructure **5.1.** Energy infrastructure **5.2.** Land transport **5.3.** Ports **6.** Emergency.	**1.** Temperature rise, **2.** Droughts, **3.** Windstorms, **4.** Heat waves, **5.** Cold invasions/frost, **6.** Extreme precipitation, **7.** Snowcover decrease, **8.** Sea level rise	Daily mean temperature (TAS) Daily max temperature (TASMAX) Daily min temperature (TASMIN) Drought during the growing season Fire weather index (FWI) Average wind speed Storminess Wind gusts Calm days Heatwave duration Tropical nights (TR20) Cold spell duration Growing season length (GSL) Heating degree days Cooling degree days Frost Precipitation amount (PR) Number of days with heavy and very heavy precipitation Maximum daily precipitation Number of days without precipitation Return period of 1% flood, change No. of days with snow cover Maximum snow cover thickness Freeze-thaw cycles Sea level rise Runoff Storm surges change

The selection of sectors, drivers, and indices was based on data availability and relevance for local planning. This formed the basis for selecting the most significant climate change impacts, which are analysed in the next steps.

Step 2.

Selection of Climate Change Impacts for further analysis: Qualitative Assessment of Exposure and Vulnerability to CC Hazards

Adaptation needs differ greatly across regions, sectors, and communities. To use limited resources effectively, it is essential to focus on the systems most at risk from climate change.

A climate risk assessment helps identify and prioritize where adaptation efforts are most urgently needed. This is especially valuable when financial and administrative capacities are limited, allowing decision-makers to focus on the most significant risks.

Risk assessments can be conducted using qualitative or quantitative methods:

- A qualitative (expert-based) approach is useful when data or methodologies are lacking.
- A quantitative approach is possible when reliable data and tools are available.

As reliable climate data are not yet available in Ukraine, we will not provide here examples of quantitative approach. One could find, however, such example in our publication «Cost-effective community-based climate change adaptation in Ukraine». Interdisciplinary Studies of Complex Systems (Kyiv, Ukraine), No. 20 (2022) 16-32, DOI[2]:

An example of a qualitative (expert-based) approach is provided below.

Full Methodology of identification, quantification and prioritization of indicators of climate change risks is provided in Annex 2.

According to this Methodology, Risk could be assessed using the following formula:

Risk(i, j, e) = Likelihood(i) × Impact(i, j, e)

(i = climate driver; j = region; e = economic sector)

In simple terms, this means that risk increases when:

- A climate hazard (e.g. drought, flood, heatwave) is more likely to occur, and
- Its impact on a specific sector or region is more severe.

Each impact is assessed using a severity scale, helping to estimate how strongly a particular climate driver (like sea level rise or extreme rainfall) could affect a sector such as agriculture, energy, or infrastructure.

2. https://doi.org/10.31392/iscs.2022.20.016

How to identify the most relevant Risks?

To prioritise action, a list of possible climate change impacts should be reviewed by considering:

- Potential impacts of the identified climate change on individual economic sectors and municipalities (whether the projected climate change impacts are significant and the relationship between the drivers of impacts and climate change impacts is scientifically sound);
- Availability of information on the current situation in the relevant sectors of the economy, at the municipal or regional level;
- Relevance of risks to the current situation in the context of existing and planned strategic documents.[3]

When Exposure and Vulnerability are hard to separate

In cases where it is difficult to assess exposure and vulnerability separately, risk can be estimated directly by calculating the relative change (Δ) in the relevant climate indicator. This is done as follows:

Δ = (Projected Value — Current Value) / Current Value

For example:

- If heatwave duration increases from 15 to 20 days:
  Δ = (20 — 15) / 15 = 0.33 → Low risk
- If sea level rises from 8 to 11.5 metres by 2100:
  Δ = (11.5 — 8) / 8 = 0.44 → Medium risk

Assessing the Likelihood, Exposure and vulnerability

To estimate risk, three components must be assessed:

1. **Likelihood**

How likely is the hazard to occur?

3. These aspects were taken into account by the project team when identifying the most important impacts and risks of climate change in Lithuania in the context of municipalities, analyzing the current situation in the relevant area and the possibilities for the municipality to influence the risks in the future. The selection was based on a comprehensive literature review, expert opinion, and consultations with responsible institutions.

Table 2:
Likelihood assessment

Scale of likelihood		Description	Chance of occurrig
Rare	1	Highly unlikely to occur	5%
Unlikely	2	Given current practices and procedures, this incident is unlikely to occur	20%
Moderate	3	Incident has occurred in a similar geographic area/sector	50%
Likely	4	Incident is likely to occur	80%
Almost certain	5	Incident is very likely to occur, possibly several times	95%

2. Exposure

Who or what is located in the affected area?

Table 3:
Exposure assessment

Exposure	Score	Chance
Negligible	0	5
Low	1	20
Medium	2	50
High	3	80
Very high	4	95

3. Vulnerability

How sensitive or unprepared is the system?

Table 4:
Vulnerability assessment

Vulnerability		
Negligible	0	5
Low	1	20
Medium	2	50
High	3	80
Very high	4	95

4. https://www.bbc.com/news/articles/c1knr8k8mlgo

Calculating Impact and Risk

Impact Formula: Impact (I) = Exposure (E) × Vulnerability (V)

In the formula I = V x E, exposure (E) is assessed as the presence of people, livelihoods, species or ecosystems, ecological functions, services and resources, infrastructure, or economic, social or cultural assets in the study area in places and conditions that may be adversely affected by climate change. For example, the exposure to sea level rise in Kyiv is zero, while the exposure to flash floods in the Carpathians can be assessed as very high. Although flash floods do occur in Kyiv.

In this case, a Vulnerability (V) is a characteristic of a population or facility in a Flood Zone (FZ) that makes them particularly vulnerable to the damaging effects of Driver D_6 (Extreme precipitation in this case). For example, it is the vulnerability of structures to flooding or the lack of early warning systems (see the recent example from Valencia[4])

Table 5:
Impact matrix

Impact matrix	Exposure					
Vulnerability		Negligible	Low	Medium	High	Very high
	Negligible	0	0	0	0	0
	Low	0	1	2	3	4
	Medium	0	2	4	6	8
	High	0	3	6	9	12
	Very high	0	4	8	12	16

Then the Impact could be assessed as:

Negligible	Low	Medium	High	Very high
0	1-3	4-6	7-11	12-16

And the risk matrix will look like this:

Impact matrix	Exposure					
		Negligible	Low	Medium	High	Very high
Vulnerability	Negligible	0	3.8	7.6	11.4	15.2
	Low	0	2.4	4.8	7.2	9.6
	Medium	0	1	2	3	4
	High	0	0.2	0.4	0.6	0.8
	Very high	0	0	0	0	0

Do not accept the risk

Risk tolerance

Accept the risk

Impact

Figure 2. *Example of a risk matrix. (Source: Figure by author).*

Step 3.

Assessment of Exposure and Vulnerability to CC Hazards

This step helps identify which areas and sectors are most at risk from climate change by analysing their exposure and vulnerability to specific climate hazards.

Exposure Assessment

To understand how different areas are exposed to climate risks, data on projected changes in climate indicators, such as temperature, precipitation, or sea level, should be used. This information is typically provided by national institutions such as the Ukrainian Hydrometeorological Centre or other official sources of climate information.

This manual draws on experience from a pilot project in Lithuania. In that context, data from the Lithuanian Hydrometeorological Service was used. For Ukraine, municipalities should rely on national data providers to ensure local relevance and consistency.

In the Lithuanian pilot, experts analysed exposure using the following criteria:

- Whether the projected changes are significant and scientifically sound;
- Availability of up-to-date information at the municipal or regional level;
- Relevance of the risks to current and planned strategic documents.

Below you can find the expert group's opinion on the exposure assessment:

Table 6:
Characterization of the degree of exposure to climate change based on changes in representative indices (opinion of the expert group, coastal zone), data based on the Lithuanian Hydrometeorological Service forecast.

Degree of Exposure			
Climatic Impact Driver, D	**D Indices, St**	**Δ for Lithuania, 2100 RCP8.5**	**Degree = 0 / 1 / 2 / 3 / 4**
1. Temperature rise	Summer daily maximum mean air tem-perature change	Δ 7,7→10,0 °C	**Medium 2**
	Change duration of the heating season	Δ 207→175 days	
	Growing season change	Δ 206→243 days	
2. Drought	Consecutive (duration) dry days —	Δ 2,1→7,0 days	**Low 1**
	Drought during the growing season	Δ 4,4 →6,3 days	
3. Windstorms	Days with maximum wind speed > 10,8 m/sec (> 6 beaufort) change	Δ 17,3 →20,1 day	
4. Heat waves	Days with maximum daily mean air temperature change	Δ 7,7→10,0 °C Δ 11,3→14,1 °C	**High 3**
	Duration of heat waves	Δ 2,1→7,0 days	
	Tropical nights change	Δ 0,5→6,5 nights	
5. Cold invasions / frost	Average annual duration of sudden frosts	Δ 9,4→6,0 days	**Negligible 0**
	Freeze-thaw cycles	Δ 66→39 days	
	Consecutive days (duration) with mini-mum mean air temperature < -10 °C (cold spell) change	day/year	
6. Extreme precipitation	Days with precipitation value	Δ 16 →20,5 days	**High 3**
	Number of heavy precipitation days, change	Δ 3,4 →4,7 days	
	Return period of 1% flood, decrease	20% (Carpathians)	
7. Snowcover decrease	Surface Snow Amount	Δ 21,5 →18,2 cm	**Low 1**
8. Sea level rise	Storm surges change (height)	%	**Very high 4**
	Sea level rise	Δ →35 cm	

Vulnerability Assessment

Vulnerability reflects how strongly a sector is affected by a specific climate hazard, depending on its sensitivity and capacity to cope.

For example:

- The water sector is highly vulnerable to droughts due to reduced water availability and increased demand.
- The fisheries sector is less affected by droughts.
- Heatwaves do not significantly impact water bodies but pose a serious risk to infrastructure and the built environment.

To assess vulnerability, experts used a vulnerability matrix, which scores how strongly each sector is affected by various climate drivers. Values range from 0 (no impact) to 4 (very high impact).

Below is a sample from the vulnerability matrix developed during the Lithuanian pilot project.

Table 7:
Vulnerability analysis matrix

Vulnerability									
Sector /Impact		**Climatic Impact Drivers**							
		1. Temperature rise	**4. Heat waves**	**6. Extreme precipitation**	**2. Droughts**	**8. Sea level rise**	**3. Windstorms**	**5. Cold invasions / frost**	**7. Snowcover decrease**
1. Public health Increased mortality and cardiac morbidity and vascular diseases		1	4	1	1	0	0	1	1
2. Agriculture	Crop loss	1	1	2	2	4	1	2	1
	Increase in diseases and pests	2	2	1	1	4	1	1	1
3. Biodiversity	Increase in diseases and pests	1	2	2	2	3	1	1	0
	Change in tree species composition	2	1	1	3	4	1	1	0
4. Water resources	Sea and fresh water quality and eutrophication	1	0	2	3	4	0	2	2
	In-creased frequency of flooding	1	0	2	4	3	0	0	0
	Coastal erosion	2	0	1	1	3	3	0	0
5. Energy	Change in demand for heating and cooling	3	4	1	2	0	1	3	1
6. Infrastructure	Urban heat island effect	3	4	1	2	4	1	1	1
	Damage to road and traffic disruption	1	1	1	2	4	1	1	1
	Disruption of services of special importance	1	1	1	1	4	3	0	0
7. Emergency Economic losses Economic losses / Increased mortality due to natural disasters		3	3	2	4	0	1	2	1

Step 4.

Selection of Climate Change Impacts for Comprehensive Response Development

To develop effective and targeted response measures, it is important to review the full list of potential climate change impacts (CCIs) provided in *Annex 1* and prioritize those most relevant to local conditions.

How to Prioritise Impacts

The selection should be based on the following criteria:

- The significance of the predicted impact on specific sectors and municipalities, and whether the link between the climate driver and the impact is scientifically sound;
- The availability of reliable data at the sectoral, municipal, or regional level;
- The alignment of identified risks with existing or planned strategic documents and policies.

Results of the Analysis

This process helped identify the most relevant climate impacts by considering:

- Local exposure levels,
- Likelihood of occurrence,
- Current vulnerability,
- Municipal adaptive capacity.

The climate impacts selected for developing integrated response measures are listed in *Table 8* below and may serve as inspiration for similar analyses in the Ukrainian context.

Table 8:
Climate change impacts selected for comprehensive response development.

Sector	Impacts selected for detailed response development
Public health	• Increased incidence of vector-borne diseases • Increased mortality and cardiac morbidity and vascular diseases • Increased respiratory morbidity diseases • Increased heat stress and thermal discomfort
Agriculture	• Crop loss • Increase in the number of diseases and pests • Soil degradation
Biodiversity, ecosystem services and forestry	• Eutrophication • Increase in diseases and pests • Forest fires • Change in tree species composition
Water resources and coastal zone	• Sea and freshwater quality and eutrophication • Coastal erosion • Increased frequency of flooding
Energy	• Change in demand for heating and cooling • Damage to electricity generation and transmission facilities and infrastructure
Infrastructure	• Damage to road infrastructure and traffic disruption • Damage to water transport infrastructure and weakening of functions • Damage to cultural heritage objects • Exacerbation of the urban heat island effect • Disrupted sewage treatment plant exploitation
Extreme situations	• Environmental pollution caused by natural disasters • Economic losses/Increased mortality due to natural disasters • Disruption of services of special importance due to infrastructure damage

Step 5.

Mapping of climate risks

Once risk levels are calculated, results should be mapped to show where the most serious risks occur across the city or region. Mapping supports:

- Communication with stakeholders,
- Prioritisation of adaptation actions, and
- Coordination across sectors.

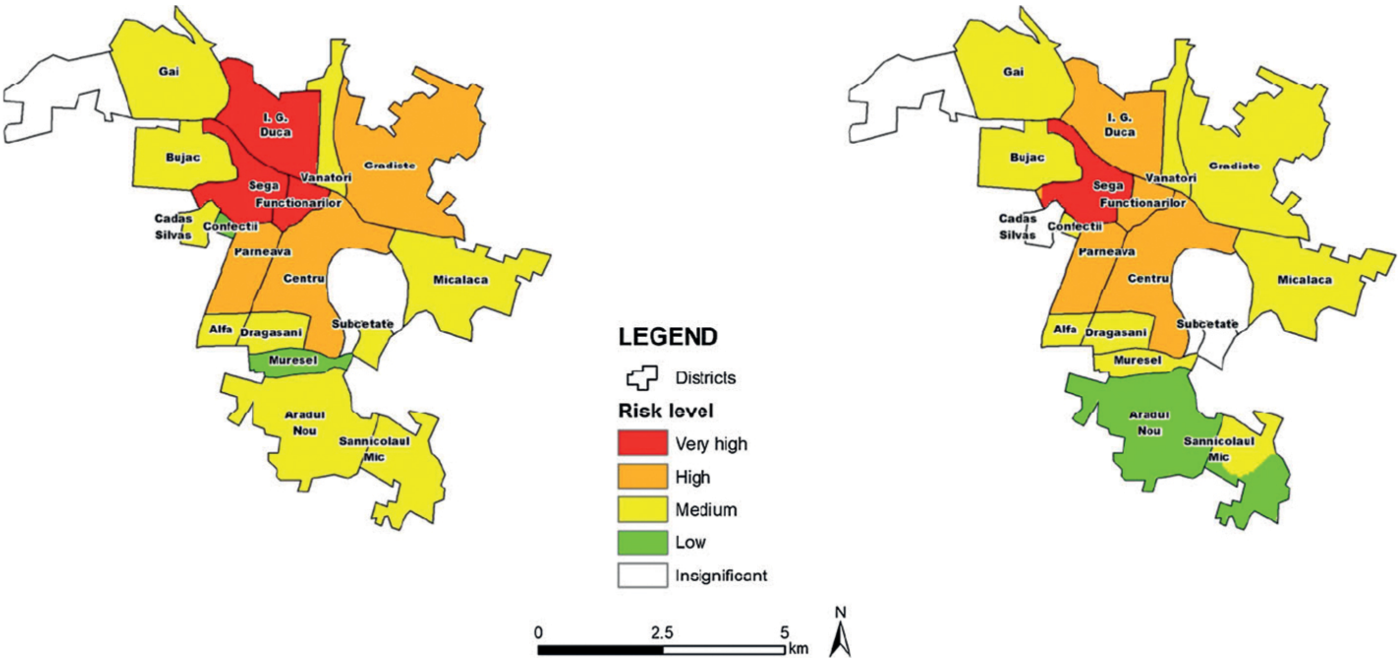

Figure 3. *Examples of heat wave risk mapping of Lithuanian municipalities.*

(Source: Figure is from the project «CLIMATE CHANGE ADAPTATION PLAN FOR THE MOST SENSITIVE MUNICIPALITIES OF LITHUANIA. Project ClimAdapt-LT.»).

The application of GIS techniques is a good tool for communication among stakeholders and can be used more easily by decision-makers and wider groups of the public. Using GIS tools, cities can visualise:

- Which hazards (e.g. heatwaves, floods) are most likely to occur;
- Which areas and assets are most exposed;
- Where vulnerabilities are highest.

Based on the numerical modeling, a map of flood risks in Kyiv could also be constructed:

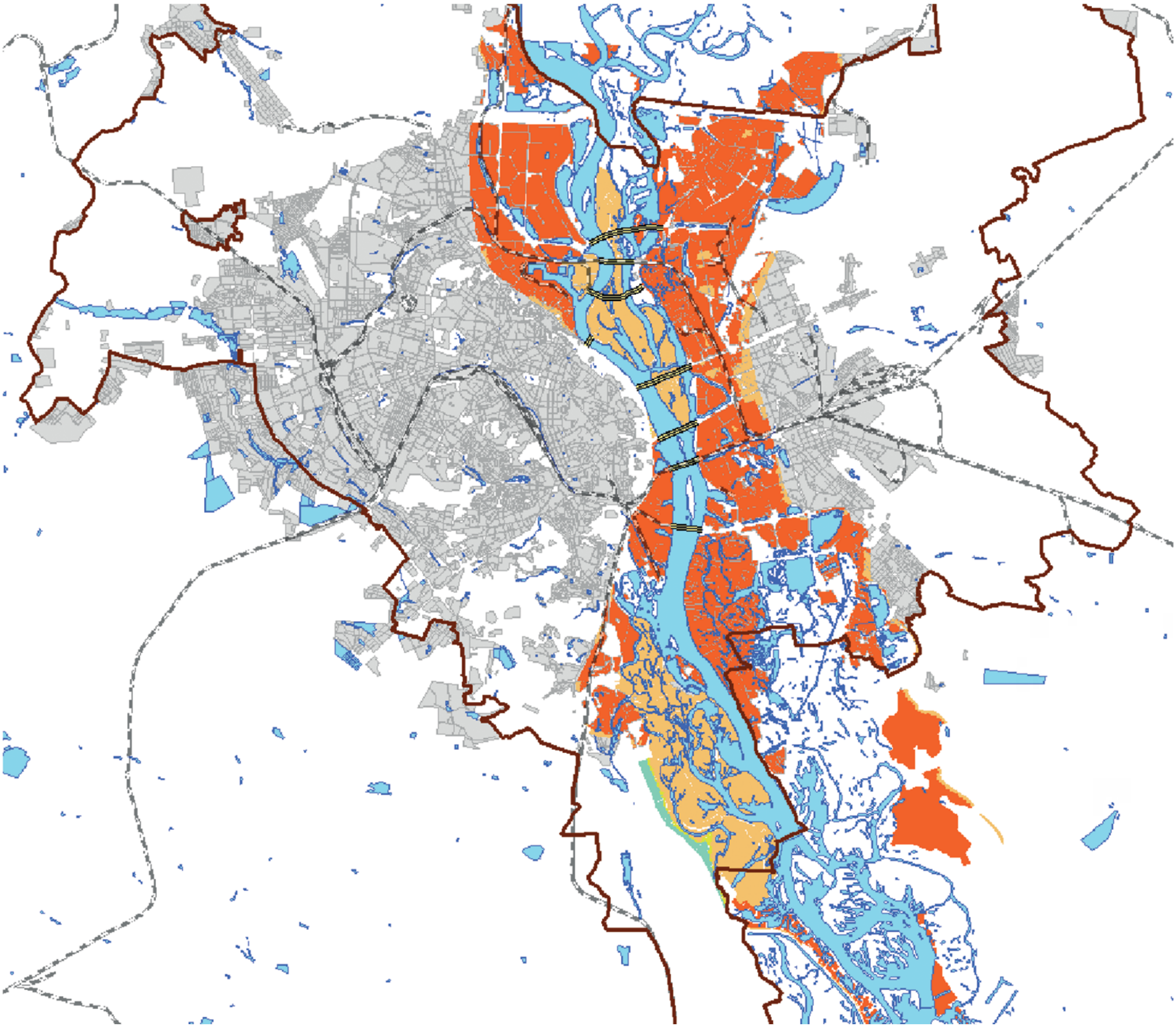

Figure 4. *General view of the flood risk map of the territory of Kyiv under the 0.1% probability scenario (once in 1000 years, with a discharge of 36394 m^3/s). Four levels of risk are indicated by different colours.*

(Source: Andriy Demydenko et al. «Cost-effective community-based climate change adaptation in Ukraine». Interdisciplinary Studies of Complex Systems (Kyiv, Ukraine), No. 20 (2022) 16-32, DOI[5])

5. https://doi.org/10.31392/iscs.2022.20.016

Annexes

Annex 1

Impact chains: Drivers of climate impacts → Potential impacts (consequences). Examples from the Lithuanian case

After several rounds of discussions, the Lithuanian project team agreed on the impact chains: Drivers of climate impacts → Potential impacts (consequences) of these drivers. In addition, the Lithuanian Hydrometeorological Service proposed projected changes in indices (Δ) for the scenario 2100 RCP8.5:

Table 9:
Projected changes in indices (Δ) for the scenario 2100 RCP8.5 in the Lithuanian case

Climatic Impact Driver, D	D Indices, St	Δ for Lithuania, 2100 RCP8.5	Potential CC impacts in different sectors, I
1. Temperature rise	Summer daily maximum mean air temperature change	Δ 7,7→10,0 °C	• Increase in morbidity from respiratory dis-eases (ID), • Increase in vector-borne diseases (VD), • Increase in water and food-borne diseases (FD), • Impact on mental health (MH), • Change in crop yields (CY), • New agricultural products (NP), • Increase in diseases and pests (IP), • Eutrophication (EU), • New invasive species (NS), • Distribution shifts and extinction of species (ES), • Forest fires (FF), • Change in forest productivity (FP), • Change in composition of tree species (TS), • Impairment of ecosystem services (ES), • Sea and fresh water eutrophication (WE), • Change in demand for heating and cooling (HC), • Damage to power generation and transmis-sion facilities and infrastructure (DA), • Exacerbation of urban heat island effect (HI), • Transport schedule disruption (TD)
	Duration of the heating season change	Δ 207→175 days	
	Growing season change	Δ 206→243 days	
2. Drought	Consecutive (duration) dry days	Δ 2,1→7,0 days	• Change in composition of tree species (TS), • Forest Fires (FF), • Reduced water quality (WQ), • Damage to arable land (DL), • Increase in windbreaks/ windfalls (WW), • Impairment of ecosystem services (ES), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Economic losses from natural hazards (ES)
	Drought during the growing season	Δ 4,4 →6,3 days	

Table 9:
Projected changes in indices (Δ) for the scenario 2100 RCP8.5 in the Lithuanian case

Climatic Impact Driver, D	D Indices, St	Δ for Lithuania, 2100 RCP8.5	Potential CC impacts in different sectors, I
3. Windstorms	Days with maximum wind speed > 10,8 m/sec (> 6 Beaufort) change	Δ 17,3 →20,1 day	• Increase in windbreaks/ windfalls (WW), • Coastal erosion (CE), • Impact on coastal tourism (CT), • Damage to power generation and transmission facilities and infrastructure (DA), • Damage and impaired functionality of road infrastructure (RI), • Damage and impaired functionality of rail infrastructure (LI), • Damage and impaired functionality of aviation infrastructure (AI), • Damage to cultural heritage sites (HS), • Impaired operations of industrial enterprises (IE), • Environmental pollution caused by natural disaster (ND), • Economic losses from natural hazards (ES), • Disruption of critical services due to damage to infrastructure (CS)
4. Heat waves	Days with maximum daily mean air temperature change	Δ 7,7→10,0 °C Δ 11,3→14,1 °C	• Increase in mortality and morbidity from cardiovascular diseases (TDE), • Increase in morbidity from respiratory dis-eases (ID), • Increase in heat stress and discomfort (DI), • Impact on mental health (MH), • Damage and impaired functionality of road infrastructure (RI), • Damage and impaired functionality of rail infrastructure (LI), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Damage and impaired functionality of avia-tion infrastructure (AI), • Damage to cultural heritage sites (HS), • Exacerbation of urban heat island effect (HI), • Impaired operations of industrial enterprises (IE)
	Duration of heat waves	Δ 2,1→7,0 days	
	Tropical nights change	Δ 0,5→6,5 nights	
5. Cold invasions / frost	Average annual duration of sudden frosts	Δ 9,4→6,0 days	• Crop loss (CL), • Change in forest productivity (FP), • Damage and impaired functionality of road infrastructure (RI), • Damage and impaired functionality of rail infrastructure (LI), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Damage and impaired functionality of aviation infrastructure (AI)
	Freeze-thaw cycles	Δ 66→39 days	
	Consecutive days (duration) with minimum mean air temperature < -10 °C (cold spell) change	d/y	

Table 9:
Projected changes in indices (Δ) for the scenario 2100 RCP8.5 in the Lithuanian case

Climatic Impact Driver, D	D Indices, St	Δ for Lithuania, 2100 RCP8.5	Potential CC impacts in different sectors, I
6. Extreme precipitation	Days with precipitation value	Δ 16 →20,5 days	• Increased morbidity as a result of flooding events (FDE), • Increased deaths and damage due to flash floods (DF), • Crop loss (CL), • Impact on groundwater and surface water quality (WQ), • Damage to arable land (DL), • Coastal erosion (CE), • Impact on coastal tourism (CT), • Impact on hydroenergy production (HP), • Damage and impaired functionality of road infrastructure (RI), • Damage and impaired functionality of rail in-frastructure (LI), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Damage and impaired functionality of avia-tion infrastructure (AI), • Damage to cultural heritage sites (HS), • Impaired operations of industrial enterprises (IE), • Impaired operation of wastewater treatment plants (TP), • Environmental pollution caused by natural disaster (ND), • Economic losses from natural hazards (ES), • Disruption of critical services due to damage to infrastructure (CS) • Damage to arable land (DL)
	Number of heavy precipitation days, change	Δ 3,4 → 4,7 days	
	Return period of 1% flood, decrease	20% (Carpathians)	
7. Snowcover decrease	Surface Snow Amount	Δ 21,5 →18,2 cm	• Damage and impaired functionality of road infrastructure (RI), • Damage and impaired functionality of rail infrastructure (LI), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Damage and impaired functionality of aviation infrastructure (AI)
8. Sea level rise	Storm surges change (height)	%	• Coastal erosion (CE), • Impact on groundwater and surface water quality (WQ), • Impact on coastal tourism (CT), • Damage and impaired functionality of water-borne transport infrastructure (TI), • Coastal flooding (CF)
	Sea level rise	Δ →35 cm	

The presented values and quantification of exposure are subject to change based on the extreme values that will come up after the evaluation of the different climate indices and different studied areas.

Annex 2

Methodology of identification, quantification and prioritization of indicators of climate change risks

For the proper qualitative and numerical quantification of risk we will use the European Environmental Agency's (EEA):[6] impact chain analysis:

Driver (D)→ Pressure (P) → State (St) → Impact (I) → Response (Re):

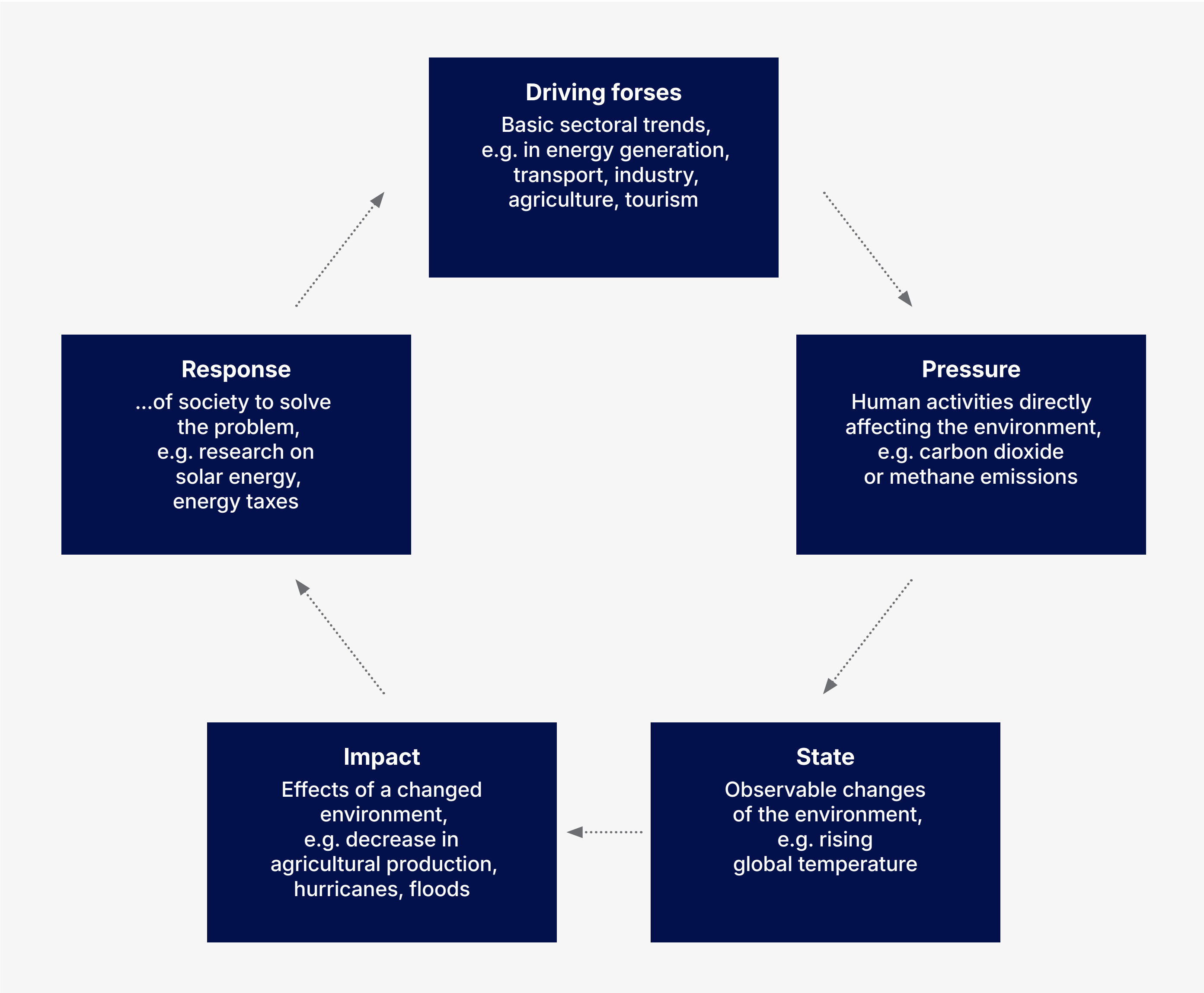

Figure 5. *Depiction of the European Environmental Agency's impact chain analysis. (Source: cf. EEA 1997[6]).*

6. https://www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html

For proper prioritization of climate change impacts, we will conduct a Climate Change (CC) Risk Assessment following international standards and the best practices, including ISO 31000:2018 Risk Management and ISO 31010:2019 Risk Management. Risk assessment methods standards, IPCC AR5[7] and AR6[8], and the best practice guidelines: *The Vulnerability Sourcebook*[9] and Assessment of *climate-related risks. A 6-step methodology*[10].

The proposed CC Risk, Impacts and Responses Assessment methodology was tested within the framework of the project[11] *«CLIMATE CHANGE ADAPTATION PLAN FOR THE MOST SENSITIVE MUNICIPALITIES OF LITHUANIA. Project ClimAdapt-LT.»*

There are a lot of discussions on how CC Risk could be assessed[12, 13] by assessing different factors in the risk formula

Risk = Likelihood x Vulnerability x Exposure

The simplest explanation for pedestrians

The simplest explanation is based on a hypothetical example of minimizing the risk of bricks falling on the heads of passers-by passing by a multi-story building site.

The likelihood (or rather the hazard) of such a risk can be reduced by reducing the number of storeys of the building. The exposure of passers-by can be reduced by choosing a path that is as far away from the building as possible. Vulnerability can be reduced by distributing helmets to passers-by or by constructing special, roofed passageways past the building.

We have successfully used such an explanation of risk multipliers (hazard probability, exposure, and vulnerability) in the WACDEP Global Water Partnership[14] project. However, in the Lithuanian project, explanations based on the example of flash flood risk assessment were more successful:

- Situation A. Area X is likely to be affected by frequent floods (high probability of floods). However, Area X lacks permanent settlements, infrastructure and economically valuable land areas (low or no risk of exposure), so the level of risk of flood-related deaths in this area is low.
- Situation B. Area X is a densely populated area with many low-rise residential buildings (high risk of impact) and is likely to be affected by frequent floods (high flood probability). The level of risk of flood deaths in this area is high because the community's vulnerability to flooding is high.
- Situation C. A certain area X is densely populated with many low-rise residential houses (high risk of impact) and it is likely to be affected by frequent floods (high flood risk probability). The area is protected by a dam, making it vulnerable to flooding risk lower compared to situation B. Also, the overall level of risk is lower in comparison with situation B.
- Situation D. A certain area X is densely populated, there are many low-rise residential buildings houses (high risk of impact) and is likely to be affected by frequent flooding (high probability of flooding). The local government has implemented a flood warning system and prepared an evacuation plan, and most buildings are insured. The level of risk of flood-related deaths and economic losses in this area, compared to situation C, is lower because the ability to adapt to floods in this area is better.

7. https://www.ipcc.ch/assessment-report/ar5/
8. https://www.ipcc.ch/assessment-report/ar6/
9. https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf
10. https://www.giz.de/en/downloads/giz2021-en-climate-related-risk.pdf
11. https://klimatokaita.lt/adaptation-to-climate-change/project-climadapt-lt/
12. https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf
13. https://www.adaptationcommunity.net/wp-content/uploads/2021/12/GIZ_CRM_ConceptPaper.pdf

Risk assessment can be performed using qualitative or quantitative methods. The first one — the expert approach — allows to determine qualitative levels of all three risk factors in the absence of available methodologies and necessary data. In the above cases, the risk level is assessed qualitatively, based on the conclusions of experts who used the methodology of the AR4 or AR5:

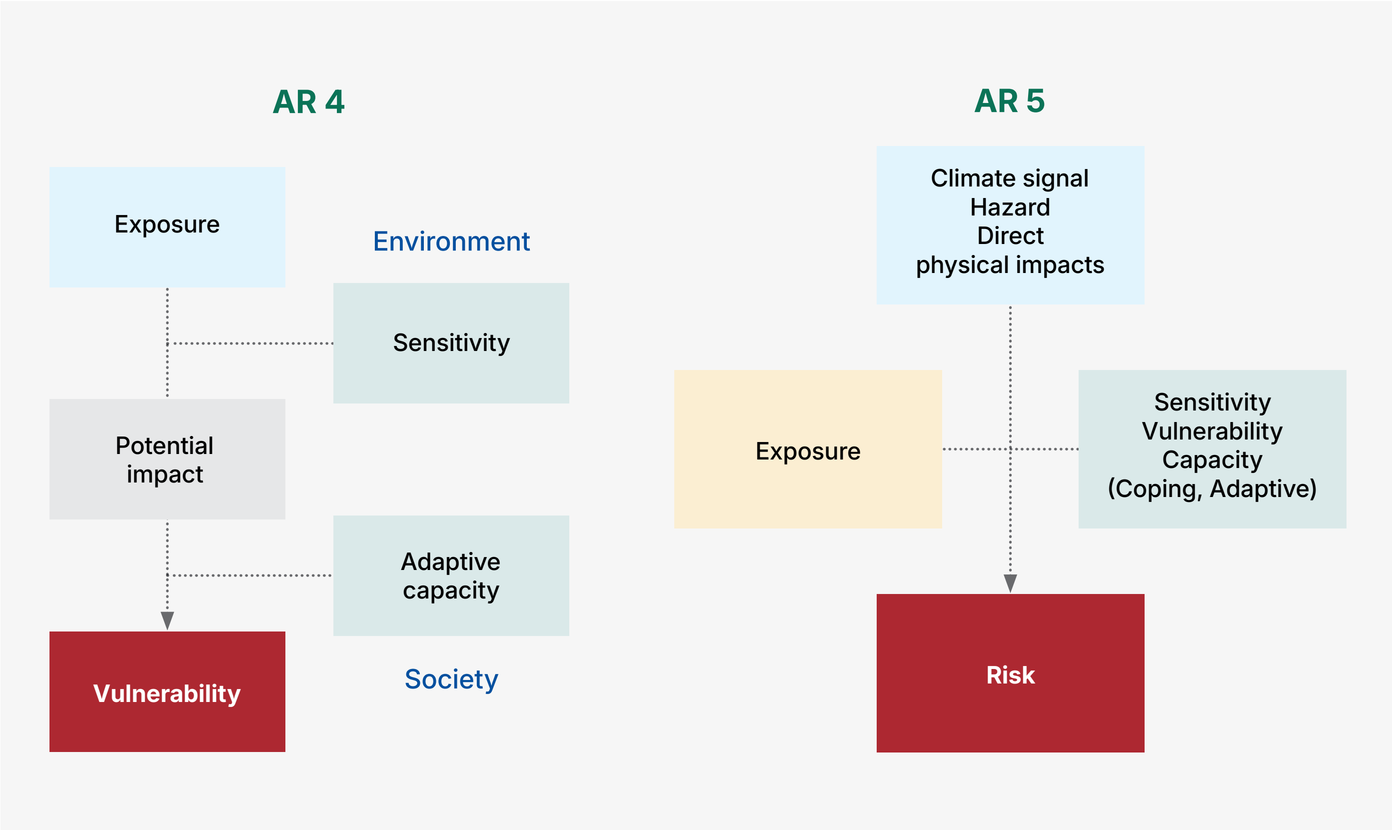

Figure 6. *Comparison of the components of climate change vulnerability (AR4) and climate risk (AR5). (Source: GIZ and EURAC 2017).*[15]

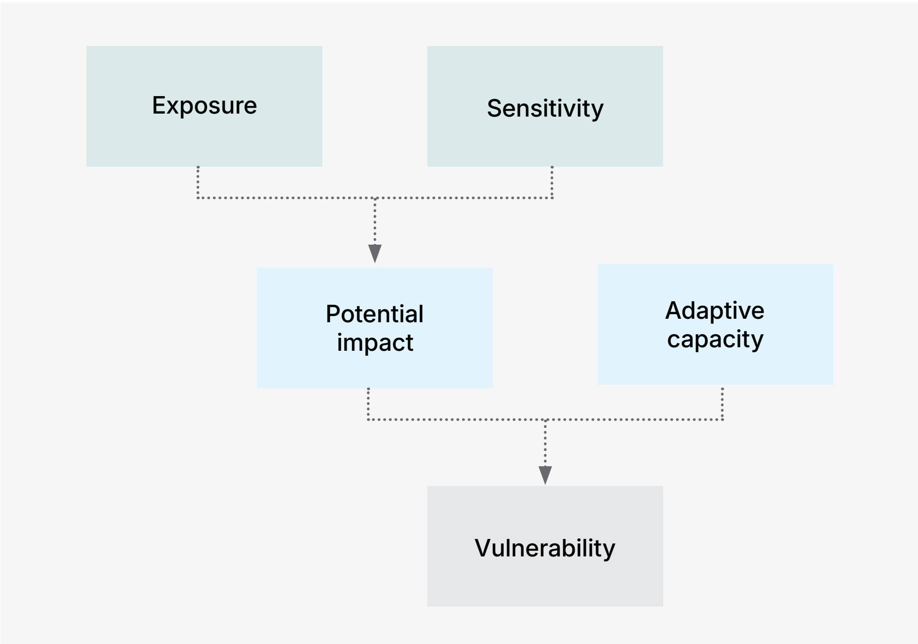

Figure 7.

Components of climate change vulnerability. (Source: cf. GIZ and EURAC 2017).[14]

Impact (I) can be estimated by the formula

I = E∗S / (E + S),

i.e. when the exposure is high, the impact is proportional to the sensitivity, I~S. But when the exposure is low, the effect is proportional to the exposure, I~E.

Vulnerability (V) can be estimated by the formula:

V = I∗A / (I + A),

i.e. when the impact is high, the vulnerability is proportional to the adaptive capacity, V~A. But when the impact is low, the vulnerability is proportional to the impact, V~I.

14. https://www.gwp.org/en/CACENA/WE-ACT/projects/Programme-goal-and-components1/

Thus, under steady-state conditions and in the harmonic approximation (when sensitivity and impact are small), impact (I) can be estimated as equal to pressure (P) and, therefore, proportional to the magnitude of change in the climate impact driver index (Δ). In this case, the vulnerability (V) and risk (R) can be estimated by experts as proportional to the change in the climate impact driver index — Δ, in the study area.

Using the example of the Lithuanian project, we have seen that in cases where experts could not get a clear idea of the magnitude of exposure or vulnerability, they proceeded to a direct assessment of the magnitude of impact based on an estimate of the magnitude of change in the climatic impact driver index — Δ.

In those cases when more data on Hazards, Exposures and Vulnerability are available, we propose to use approach of GIZ Guidelines[15]

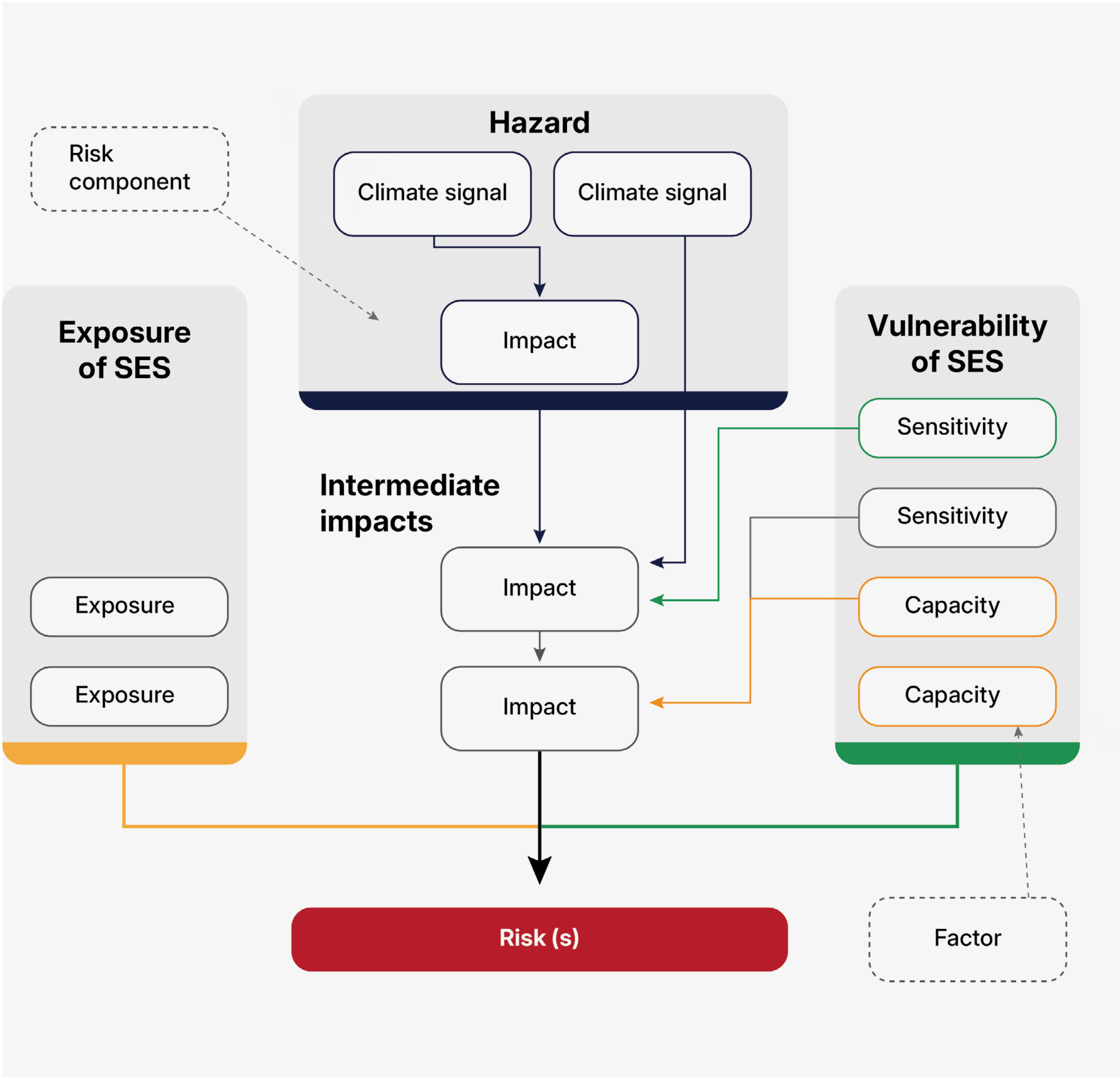

Figure 8. *Structure and key elements of an impact chain (Source: GIZ and EURAC 2017[16]).*

15. GIZ-2017_Risk-Supplement-to-the-Vulnerability-Sourcebook.pdf
16. (GIZ, EURAC & UNU-EHS (2018): Climate Risk Assessment for Ecosystem-based Adaptation — A guidebook for planners and practitioners. Bonn: GIZ., https://www.adaptationcommunity.net/wp-content/uploads/2018/06/giz-eurac-unu-2018-en-guidebook-climate-risk-asessment-eba.pdf)

where Risk is assessed by formula

Risk ~ E * H * V,

Vulnerability (V) in turn, can be estimated by the formula:

V = S/A,

where S is the sensitivity and A is the adaptive capacity, because V is proportional to S and inversely proportional to A. Given that the Rs (Resilience) is inversely proportional to the sensitivity — Rs ~ 1/S, the Risk formula for calculating the risk assessment will be as follows:

Risk ~ H*E*S/A,

Risk ~ H*E/Rs*A.

This approach makes it possible to assess the effectiveness and efficiency of risk reduction by reducing each of its multipliers.

As a reminder, the key to the success of onboarding plans is to show investors what risk multipliers you are going to reduce and how you are going to reduce them.

When evaluating risk mitigation measures according to the formula **Risk ~ H*E*S/A**, Hazard (H) and exposure E are assessed now largely numerically, and sensitivity S and adaptive capacity A are assessed largely using expert assessment due to the lack of data and methods. Expert assessment does not allow you to calculate absolute values of risks, but allows you to provide relative, comparative risk assessments. For example, by modeling certain measures to reduce the sensitivity of S and increase the adaptive capacity A, it is possible to choose the most effective and profitable methods of risk reduction.

Here are some examples of the application of the Risk formula **Risk ~ H*E*S/A** for the situation in Ukraine, where, according to Svitlana Krakovska's Overall climate change impact assessment for Ukraine[17], the most significant Hazards are:

1. Extreme heat.
2. Fire hazard and
3. Extreme precipitation for the following climate change impacts:
   - food impact,
   - health impact,
   - infrastructure impact.

For **food impact** from Extreme heat H1, we can assess the risk as follows:

Risk ~ H1*(1/Aag)*(E1*S1 + E2*S2 + ...)/(E1 + E2 + ...), where

Aag — adaptive capacity of the agricultural sector;

E1, E2 — density of agricultural crops 1, 2 per km^2;

S1, S2 — sensitivity of crops 1, 2 to the Extreme heat H1 impact.

17. https://ukrainian-climate-office.org/en/knowledge-hub/overall-climate-change-impact-assessment-for-ukraine/

For the **health impact** of Extreme heat H1, we can assess the risk as follows:

Risk ~ H1*(1/Aconst)*(E1*S1 + E2*S2 + ...)/(E1 + E2 + ...), where

Aconst — adaptive capacity of the municipal planning sector;

E1 — the amount of shaded or greenery area per km^2,

E2 — the amount of unshaded or not covered with greenery area per km^2,

S1 — people's sensitivity to heat in shaded or greenery rooms,

S2 — sensitivity of people to Extreme heat H1 in unshaded or not covered with green spaces.

For **health impact** from Fire hazard H2, we can assess the risk as follows:

Risk ~ H2*(1/Awatmgmt)*(E1*S1 + E2*S2 + ...)/(E1 + E2 + ...), where

Awatmgmt — adaptive capacity of the water management system;

E1 — Number of moistened peatlands per km^2,

E2 — Number of drained peatlands per km^2,

S1 — sensitivity of moistened peatlands to Fire hazard impact,

S2 — sensitivity of drained peat bogs to Fire hazard impact

For **infrastructure impact** of Extreme precipitation, we can assess the risk as follows:

Risk ~ H3*(1/Acses x (E1*S1 + E2*S2 + ...)/(E1 + E2 + ...), where

Acses — Adaptive capacity of the State Emergency Service;

E1 — number of wooden, unprotected or pileless houses in the flood zone,

E2 — number of concrete, sheltered, or pile houses in the flood zone,

S1 — sensitivity (degree or cost of damage) of wooden, unprotected or non-pile houses in the flood zone to flash flooding,

S2 — sensitivity (degree or cost of damage) of concrete, sheltered or pile houses to H3 Extreme precipitation

By selecting different exposure and sensitivity values, it can be estimated in advance how by changing crops, expanding green spaces, moistening peatlands, protecting homes in the flood zone, **health, food and infrastructure** risks can be reduced or underwritten. If any parameters E, S or A cannot be calculated, a high-quality expert assessment of these parameters should be used, covering the widest possible range of stakeholders.