



The HuT

Quantitative and multi-criteria analyses for multi-risk DRR

Deliverable D3.4

DEVELOPED WITHIN

WP3 Governance and policy, T3.2 Robust decision support tools for multi/systemic risk
policy making

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1.1. Document history

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3. Introduction

3.1. Foreword: background of stakeholder-led quantitative and multi-criteria analysis for policy-making

Deliverable 3.4. has the aim of summarizing the implemented activities in the T3.2 Subtask 1 “Quantitative and multi-criteria analyses for multi- and systemic risk policy making”. This subtask was carried out to develop innovative extensions for addressing multi- and systemic risks. The innovative extensions originate from the stakeholder-led process in collecting integrated disaster risk reduction and climate change adaptation measures for systemic risk and multiple risks under climate extremes in the real-world demonstrator setting instead of the modelling approach. The stakeholder-led process applies the co-design and co-development approach addresses the robustness of the multi-criteria analyses which could support decision-making. The co-design process that the stakeholders (for instance decision-makers and citizens) are engaged at the beginning of and throughout the co-design processes, and this co-design approach accelerates the implementation of integrated disaster risk reduction and climate change adaptation measures. The stakeholder-led process also includes the societal data from the real-world setting in the Demonstrator.

In this report, the methodology is described how the innovative extensions were developed for the demonstrators in The HuT. Then it is illustrated in how this methodology was applied and implemented in the first Demonstrator (Glückstadt). During the implementation phase, a pure quantitative analysis was not possible due to the real-world setting of the selected Demonstrator (availability of quantitative data, stakeholder-led process and demands). This is in-line with the The HuT approach and philosophy that activities in the work packages and tasks take place with real implementation together with Demonstrators.

Furthermore, we describe how this approach could be adapted to three additional transferrable settings, based on the types of multi-risks faced by other Demonstrators. This demonstrates how the methodology could be applied and extended in future action plan activities. The action plan in this report forms the basis for further transferability and scalability of the methodology across other Demonstrators within and beyond The HuT. This plan will be further implemented under WP1 for ongoing Demonstrator activities and WP5 to support transferability and upscaling efforts. This roadmap of firstly applied in one Demonstrator, and later on to be followed up and scaled up in WP1 and WP5 has been previously agreed and approved together with the principal investigators during the General Assembly in Valencia in 2023 and the reviewers during the mid-term review meeting.

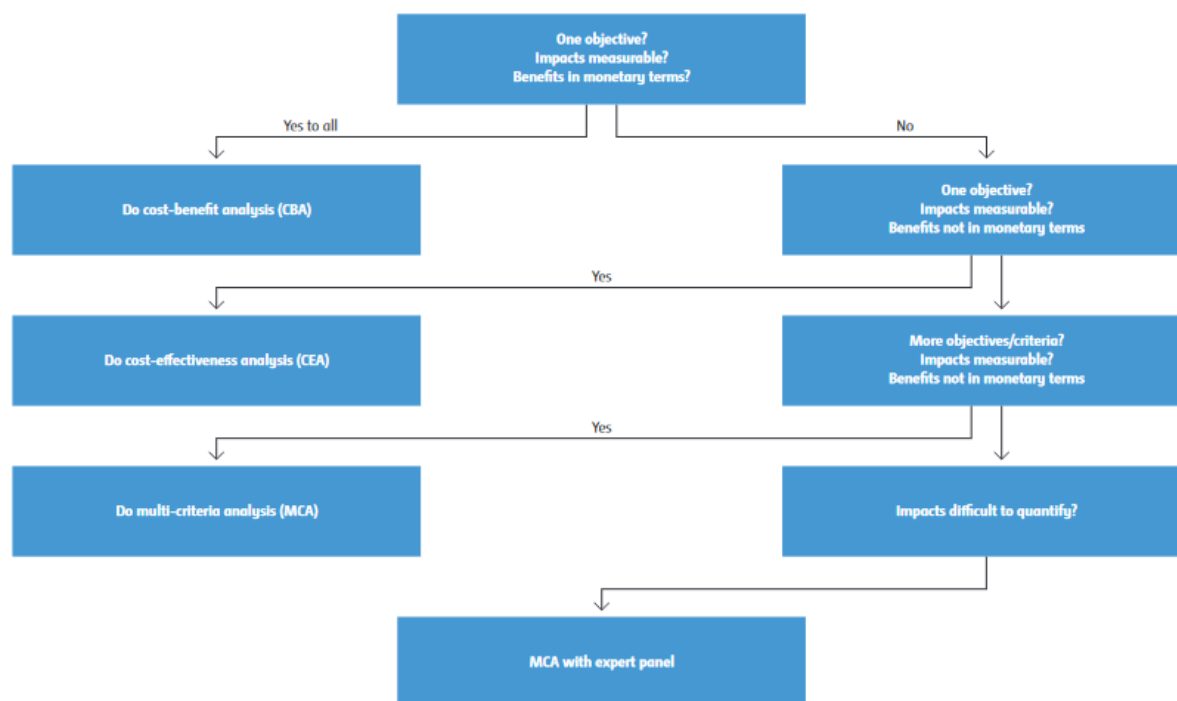
For quality assurance, in addition to the internal review process within The HuT, the application of T3.2 Subtask 1, “Quantitative and Multi-Criteria Analyses for Multi- and Systemic Risk Policy Making,” was presented at international conferences, such as European Geosciences Union (EGU), and at an MCDA-specialized workshop in front of MCDA experts in Germany and the EU.

3.2. Methodology overview

When assessing Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) measures for urban areas, decision-makers must rely on comprehensive decision-support tools to systematically prioritize options based on a range of defined criteria and sub-criteria (Barquet &



Cumiskey, 2018). These tools often include methodologies such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA). The selection of an appropriate tool is contingent upon the extent to which the objectives, impacts, and benefits of the measures can be quantified in monetary terms (UNFCCC, 2011; Boyd & Hunt, 2004).



Source: Adapted from BOYD R AND HUNT A. 2004. *Costing the Impacts of Climate Change in the UK: Overview Guidelines*. UK Climate Impacts Programme Technical Report.

Figure 1: Decision tree of possible approaches for assessing the costs and benefits of adaptation options (Source: UNFCCC, 2011, p11; Boyd & Hunt, 2004).

3.2.1. Introduction of cost-benefit analysis

Cost-benefit analysis (CBA) is a systematic approach used to evaluate the economic efficiency of proposed projects or policies by comparing their costs and benefits over time (Boardman et al., 2018). In the context of DRR and CCA measures, CBA helps decision-makers assess the economic viability of different interventions by monetizing their impacts. The primary steps in conducting a CBA include:

- Identifying all costs and benefits associated with each alternative
- Quantifying these costs and benefits in monetary terms
- Discounting future costs and benefits to present values
- Calculating net present values (NPV) or benefit-cost ratios (BCR)
- Performing sensitivity analyses to account for uncertainties

CBA is particularly useful when the costs and benefits of alternatives can be reliably quantified in monetary terms (UNFCCC, 2011). For instance, it can effectively evaluate structural measures like improving climate dikes or maintaining drainage systems, where both implementation costs and potential damage reduction can be estimated.



However, CBA has limitations when dealing with intangible impacts or long-term environmental effects that are difficult to monetize (Hallegatte et al., 2012). It may also struggle to account for distributional effects or equity considerations, which are often crucial in DRR and CCA decision-making (Mechler, 2016).

3.2.2. Introduction of cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a decision-support tool used to compare the relative costs of interventions in relation to their outcomes, which are measured in non-monetary units. In the context of DRR and CCA, CEA is particularly valuable when the benefits of interventions cannot easily be monetized but can be expressed in terms such as lives saved or areas protected (Mechler, 2016). It serves as a primary alternative to CBA, evaluating the trade-offs between the costs of interventions and their effectiveness. Unlike CBA, which monetizes benefits, CEA assesses benefits in non-monetary units, making it especially useful when monetizing outcomes are impractical, controversial, or uncertain (Boyd & Hunt, 2004).

The main steps in conducting a CEA include:

- Defining the objective and outcome measures
- Identifying alternative interventions
- Estimating the costs of each intervention
- Estimating the effectiveness of each intervention
- Calculating cost-effectiveness ratios
- Conducting sensitivity analyses

CEA is typically expressed as a ratio of cost to a specific measure of effectiveness, such as cost per life saved or cost per hectare of land protected from flooding (Tanner et al., 2015). This allows decision-makers to compare interventions that vary in scale but share a common outcome measure.

In the context of climate change adaptation, CEA serves two key purposes: identifying the least-cost adaptation strategy to achieve a specified level of climate risk management and assessing cost-based approaches to quantify the economic losses avoided through reduced climate-induced damages (Boyd & Hunt, 2004). One of the principal advantages of CEA in DRR and CCA is its ability to compare interventions with diverse outcomes that are not easily monetized. For instance, it can evaluate the cost-effectiveness of early warning systems, evacuation plans, and structural defenses in terms of potential lives saved.

CEA does not determine whether an intervention is inherently worthwhile, but rather how it compares to alternatives (Levin & McEwan, 2001). Also, it may not fully capture the multiple or complex outcomes that characterize many DRR and CCA interventions, and it is not designed to compare interventions with fundamentally different outputs (Boyd & Hunt, 2004).

3.2.3. Introduction of multi-criteria analysis

Multi-criteria analysis (MCA) is frequently employed as a decision-making tool, particularly when assessing alternatives that must be evaluated against locally relevant, and sometimes intangible, criteria. Unlike other methods, MCA encompasses a diverse set of techniques and tools that facilitate the ranking of alternatives based on multiple criteria and sub-criteria (Dean, 2022; Saaty, 2008). MCA is particularly valuable when decision-makers face complex, multidimensional challenges that cannot be fully captured through quantitative measures alone.



As Dean (2022) outlines, the fundamental components of MCA include the following:

- **Alternatives:** Proposed options designed to address a specific challenge or to achieve a defined objective.
- **Objectives:** The specific goals against which the proposed alternatives are assessed.
- **Criteria:** Measurable indicators used to evaluate how well the alternatives meet the objectives.
- **Performance scores:** A numerical evaluation (e.g., on a scale from 0 to 1, 1 to 100, or -2 to 2) representing the degree to which each alternative satisfies the criteria.
- **Criterion weights:** Values assigned to reflect the relative importance of each criterion in achieving the stated objectives.

MCA can be conducted through both **non-participatory** and **participatory** approaches. In non-participatory MCA, an analyst or a team of analysts processes data independently and presents the findings to decision-makers. In contrast, a **participatory MCA** incorporates the direct involvement of stakeholders, including affected parties, experts, and decision-makers, ensuring that diverse perspectives are integrated into the decision-making process. The advantage of the participatory approach lies in its ability to capture a broad range of viewpoints, fostering more inclusive and contextually relevant outcomes (Mühlbacher & Kaczynski, 2016).

3.2.3.1. Participatory Multi-Criteria Analysis

Participatory MCA combines the analytical rigor of traditional MCA with the benefits of stakeholder engagement, giving robust, transparent and locally acceptable solutions (Antunes et al., 2006). It allows for the integration of diverse perspectives, including local and expert opinions, which is crucial when dealing with the uncertainties inherent in climate change and disaster risk (Kiker et al., 2005). Additionally, participatory MCA facilitates the consideration of both quantitative and qualitative criteria, making it particularly suitable for situations where not all impacts can be monetized or quantified (Huang et al., 2011).

The participatory approach involves stakeholders throughout the decision-making process, from problem structuring to criteria selection and weighting (Mustajoki et al., 2004). This engagement not only enhances the legitimacy of the decision-making process but also builds consensus and facilitates the implementation of chosen alternatives (de Brito & Evers, 2016).

By involving a diverse group of stakeholders, including local residents, municipal workers, and experts, the process aims to identify and prioritize DRR and CCA measures that are both effective and locally appropriate (Grafakos et al., 2019).

3.2.3.2. Non-participatory Multi-Criteria Analysis

Non-participatory MCA is a structured approach to decision making that relies primarily on expert judgment and available data without direct stakeholder involvement in the analysis process (Huang et al., 2011). This method is particularly useful in situations where technical expertise is crucial, time is limited, or when dealing with highly complex issues that may be challenging for non-experts to fully grasp.

In the context of DRR and CCA, non-participatory MCA allows for a more controlled and consistent analytical process, potentially reducing biases that might arise from stakeholder interactions (Linkov & Moberg, 2011). This approach is often more efficient in terms of time and resources, making it suitable for urgent decision-making scenarios (de Brito & Evers, 2016).

This methodology typically involves a team of experts or analyst who define the problem, identify alternatives, establish criteria, assign weights, and evaluate opinions bases on available data and



their professional judgment (Belton & Stewart, 2002). It can be particularly effective when dealing with quantitative data and when there is a need for specialized knowledge to interpret and analyze information. However, while it can provide valuable insights, it may miss important local perspectives and face challenges in the implementation due to the lack of stakeholder perspectives (Grafakos et al., 2019).

Non-participatory MCA can be used to provide an initial assessment of DRR and CCA measures, which could be refined through stakeholder engagement in later stages of the decision-making process.

Here's an overview of common Multi-Criteria Decision Analysis (MCDA) methods (Mühlbacher & Kaczynski, 2016):

1. AHP (Analytic Hierarchy Process): Breaks down a decision into a hierarchy, using pairwise comparisons to rank alternatives based on weighted criteria. Simple and widely used but can be subjective.
2. ANP (Analytic Network Process): Extends AHP by allowing interdependencies between criteria. More complex than AHP.
3. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution): Ranks alternatives based on their proximity to an ideal solution. Simple and efficient but assumes compensatory criteria.
4. ELECTRE (Elimination Et Choix Traduisant la Réalité): Outranking method that compares alternatives pairwise to eliminate dominated ones, handling conflicting criteria well.
5. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations): An outranking method that ranks alternatives based on preference functions and pairwise comparisons.
6. WSM (Weighted Sum Model): Simple method where each criterion is weighted and summed for each alternative to get a total score.
7. MAUT (Multi-Attribute Utility Theory): Uses utility functions to evaluate and rank alternatives based on individual preferences for each criterion.
8. SAW (Simple Additive Weighting): Similar to WSM, but assumes criteria are commensurable and directly summed after weighting.

Given the complexity of decision-making in DRR and CCA contexts, it is fundamental to understand the strengths and limitations of each analytical approach. While the choice of method depends on the specific context and data availability, a comprehensive understanding of these tools can enhance the decision-making process. This approach aligns with the growing recognition in disaster risk management and climate adaptation fields that effective solutions must be co-designed with the communities they aim to protect (Barquet & Cumiskey, 2018).

3.3. Methodological Approach

For the Glückstadt demonstrator, a participatory MCA approach was selected as the primary methodology, given the several factors specific to the local context and the nature of the decision-making process required for DRR and CCA measures. Participatory MCA allows us to involve a broad spectrum of citizens and find out their local insights.



Rationale for selecting participatory MCA:

1. **Complex multi-hazard environment:** Glückstadt faces multiple hazards including storm surges, flooding, and heat waves. MCA is particularly suitable for such complex environments where multiple objectives need to be considered simultaneously.
2. **Qualitative and quantitative data:** The available data in Glückstadt included both quantitative (e.g., flood levels) and qualitative (e.g., stakeholder preferences) information. MCA can effectively incorporate both types of data.
3. **Stakeholder engagement:** The participatory approach was chosen to ensure local knowledge and preferences were incorporated, enhancing the legitimacy and acceptance of the final decisions
4. **Limited monetary valuation:** Many of the benefits of DRR and CCA measures in Glückstadt were difficult to monetize, making traditional cost-benefit analysis challenging.
5. **Transparency and accountability:** The structured nature of MCA provides a clear and traceable decision-making process, which is crucial for public policy decisions.

3.3.1. Potential Application of the Methodology in Other DEMs

The Participatory MCA approach applied in DEM5 serves as a robust framework for decision-making in DRR and CCA. This methodology can be adapted to other DEMs, considering their specific contexts, data availability and stakeholder engagement processes. The flexibility of the methodology allows for its integration with other decision-making tools (hybrid approach), such as CBA and CEA, where relevant providing a comprehensive assessment framework tailored to the unique challenges for each DEM and their systemic risk challenges.

3.3.1.1. Heatwaves and health impacts

Heatwaves and health impacts (DEM1: Valencia, Spain). In DEM1 (Valencia), the primary systemic risk involves heatwaves and their cascading impacts on public health and urban infrastructure. The participatory MCA approach applied in DEM5 can be effectively adapted to this context by engaging a diverse group of stakeholders, including local health authorities, urban planners, climate scientists, and representatives from vulnerable communities.

To effectively adapt the methodology applied in DEM5 to DEM1, it is necessary to consider a series of key steps that will ensure the methodology addresses the specific challenges posed by heatwaves in Valencia's urban landscape. These steps include stakeholder engagement, criteria development, exploring alternative measures, evaluation process, integration with complementary analyses, and sensitivity analysis.

For stakeholder engagement, all the workshops should be designed to gather input from key stakeholders on potential adaptation measures and establish the evaluation criteria. In some cases, the Delphi method can be used to reach expert consensus on heatwave risk projections (Linstone & Turoff, 2002). The criteria development should focus on effectiveness, quantified by reduction in heat-related illnesses and mortality (Toloo et al., 2013); economic feasibility, considering implementation and maintenance costs; equity, ensuring protection for vulnerable populations; environmental co-benefits, such as reduction in urban heat island effect; and resilience, assessing the ability to function during extended heatwave periods.

For this systemic risk, the alternative measures that can be explored can include urban greening initiatives, building retrofits, public cooling infrastructure, and early warning systems with public health communication strategies. The evaluation process should employ a pairwise comparison



method for criteria weighting and use expert judgment alongside available quantitative data for scoring alternatives.

One of the advantages of implementing a participatory MCA is that it can be complemented with other analyses, such as CBA – that can be used for measures with clear economic impacts – and CEA – that helps with comparing interventions that achieve similar outcomes but with different costs. However, it is still important to consider the adoption of sensitivity analysis, that should be conducted to account for uncertainties in climate projections and intervention efficacies.

Adapting the participatory MCA framework from DEM5 and integrating it with complementary economic analyses, DEM1 can establish a comprehensive, stakeholder-driven strategy for heatwave adaptation. This approach allows for the consideration of both quantitative and qualitative factors, ensuring that the selected interventions are not only economically viable but also socially equitable and environmentally sustainable.

3.3.1.2. Intense precipitation and urban flooding

In DEM4, Vilnius, Lithuania, the primary systemic risk involves intense precipitation leading to urban flooding. While CEA can be valuable in this context, the participatory MCA approach applied in DEM5 can be effectively adapted and integrated to provide a more comprehensive evaluation framework.

To adapt the DEM5 participatory MCA methodology to DEM4, several key steps must be followed to effectively address the urban flooding challenges in Vilnius. These steps include engaging stakeholders, developing relevant criteria, exploring alternative mitigation measures, conducting a thorough evaluation process, and integrating complementary analyses for a comprehensive assessment.

For stakeholder engagement, workshops should be organized to gather input from key stakeholders such as urban planners, water management authorities, local residents, and businesses affected by flooding. These workshops can help identify potential flood mitigation measures and establish evaluation criteria that reflect local priorities and concerns.

Criteria development should focus on effectiveness (e.g., reduction in flood-prone areas), economic feasibility (implementation and maintenance costs), environmental impact (e.g., water quality improvements), social equity (protection for vulnerable neighborhoods), and resilience (ability to cope with future climate scenarios).

Alternative measures to be explored can include improved drainage systems, green infrastructure solutions (e.g., rain gardens, permeable pavements), flood retention areas, and early warning systems. The evaluation process should employ a pairwise comparison method for criteria weighting and use both expert judgment and available quantitative data for scoring alternatives.

One of the strengths of the participatory MCA is its ability to integrate with other analytical approaches. In this case, CEA can be incorporated within the MCA framework to provide more detailed cost-effectiveness information for measures where such data is available. For instance:

1. Define specific objectives (e.g., reduce flood-prone areas by X%).
2. Estimate costs of each measure identified through the participatory process.
3. Quantify effectiveness in non-monetary terms (e.g. area protected from flooding).
4. Calculate cost-effectiveness ratios to compare measures.

These CEA results can then be used as inputs for one of the criteria in the broader MCA framework.



The participatory MCA methodology can be scaled and adapted to Vilnius by:

- Using Vilnius-specific flood risk maps and precipitation data in the evaluation process.
- Adapting criteria and their weights to reflect local priorities (e.g., critical infrastructure protection).
- Engaging local engineering experts and affected communities to refine cost and effectiveness estimates.

3.3.1.3. Multiple flooding under climate extremes

For the Tiza region (DEM7) the systematic risk identified involves complex flooding scenarios under climate extremes, similar to Glückstadt's multi-hazard environment. While specific flood management tools are valuable, the participatory MCA approach applied in DEM5 can be effectively adapted and integrated to provide a comprehensive evaluation framework that addresses the region's unique challenges.

For the adaptation of the methodology in the stakeholder engagement, the workshops should be organized in a manner that can allow for the consideration of a diverse range of stakeholders, including water management authorities, agricultural representatives, local communities, and transboundary partners. Workshops should be organized in a way that can help identify potential management measures and establish evaluation criteria that reflect the complex nature of the Tisza region's flooding challenges.

The criteria development should focus on effectiveness (e.g. reduction in flood frequency and severity), economic feasibility, environmental impact, social equity (protection for vulnerable communities, and regional scalability (applicability across multiple flood zones).

Some of the alternative measures that can be explored (other word for explored) can be both structural and non-structural solutions, for example, dikes and flood reservoirs or land use planning and early warning systems. The evaluation of these alternatives should employ participatory methods for criteria weighting and alternative evaluation, ensuring that local knowledge and preferences are fully incorporated.

In this case, the participatory MCA can be integrated to a CBA in order to provide a more detailed economic information for large-scale flood prevention infrastructure. For example: quantifying long-term economic benefits of major infrastructure projects, estimate costs and benefits across different flooding scenarios or incorporate these CBA results as inputs for economic criteria in the broader MCA framework. This hybrid approach allows for the consideration of both quantitative economic data and qualitative factors such as social acceptability and environmental impacts; it ensures that the selected interventions are not only economically viable but also aligned with regional needs and priorities.

The participatory MCA methodology can be scaled and adapted to the Tisza region by:

- Adjusting the process to account for the unique river basin management context and seasonal flooding patterns.
- Incorporating criteria related to transboundary water management where relevant.
- Engaging stakeholders from multiple countries if the flooding impacts cross national borders.

3.3.1.4. Preparedness for Systemic Risks of Hydrometeorological Events

The final group of Demonstrators, including DEM6 (East Fjords), DEM8 (Oglastra), DEM9 (Dorset), and DEM10 (Berne Canton), focuses on preparedness for hydrometeorological risks. In these



contexts, the participatory MCA can guide the prioritization of preparedness measures based on community needs and expert input. This approach allows for a comprehensive evaluation that considers both quantitative outcomes and qualitative factors.

The application of this methodology in these DEMs would involve engaging a diverse range of stakeholders, such as local governments, emergency services, community organizations, and residents, to collaboratively identify and evaluate potential preparedness measures. Key criteria for this analysis might include preparedness capacity (the ability of existing systems to manage future risks), cost-effectiveness (balancing the costs and benefits of early warning systems or emergency response infrastructure), and public perception (the level of acceptance and engagement with preparedness measures).

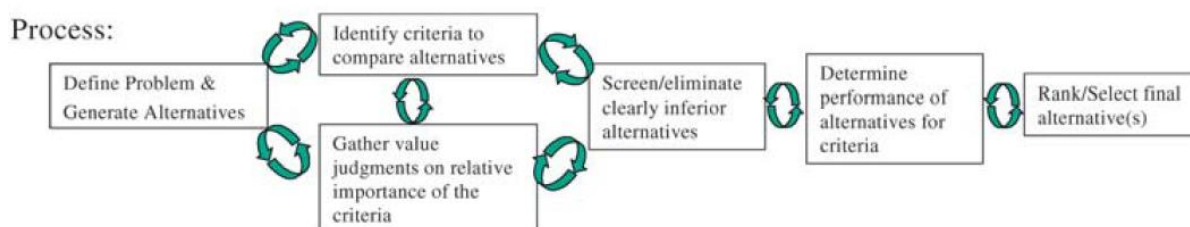
In addition to the participatory MCA framework, integrating complementary analytical tools such as CBA and CEA can enhance the evaluation process. CBA can quantify the economic benefits of implementing specific measures, such as reduced response times or lives saved during emergencies. CEA can assist in comparing interventions that achieve similar outcomes but differ in costs, providing a nuanced understanding of their effectiveness.

This hybrid approach, combining quantitative data (e.g., statistical models predicting the impacts of flooding) with qualitative insights (e.g., community feedback on preparedness strategies), ensures that all relevant factors are accounted for. It not only reinforces the technical rigor of preparedness strategies but also promotes social equity by integrating diverse stakeholder perspectives.

3.4. Stakeholder-led multi-criteria analysis with qualitative data

Information about stakeholder preferences may not be presented to the decision maker which sometimes leads to the challenge of the decision process being reliable and fair (Kiker et al., 2005). Information from scientific perspective and stakeholder's views and values should be taken into consideration before ranking the alternatives. Accordingly, decision makers are able to identify all feasible alternatives and make an informed decision.

There are many different multi-criteria analyses with their comparative strengths and weaknesses. However, in the general, the methodological process of conducting a multi-criteria analysis comprises of:



Source: Kiker et al. 2005

There are several methods to incorporate participatory process in the multi-criteria analysis steps, including:

- Interactive sessions (workshops and focus groups) where stakeholders collaborate on defining the problem, generating alternatives, identifying criteria, and determining the performance of the criteria
- Delphi method where stakeholders provide input through several rounds of anonymous surveys to build a consensus
- Voting which can be useful in case reaching consensus is difficult

One or combination of the methods can be selected depending on the local conditions. Nevertheless, there are a few parameters that first need to be considered whether a participatory multi-criteria analysis can be conducted in a city:

1. Potential of stakeholder engagement

It should be considered whether the stakeholder groups and their function in DRR and CCA in the respective city are well defined and whether the representative of the stakeholder groups are willing to collaborate in the decision-making process.

2. The availability of data and knowledge

Including qualitative and quantitative data, technical expertise, and local knowledge in terms of experience and insights from local communities

3. Institutional and governance

Whether the city governance enables and supports the participatory decision-making process and whether local government has the flexibility to incorporate the results into the actual policy recommendation.

4. Hazard and vulnerability context

Does the city have a well pre-defined hazard and vulnerability profile; and whether the most affected communities are involved in the decision making

5. Feasibility of conducting participatory multi-criteria analysis

Timeframe or time required for the participatory approach would determine the method and activities fit for the purpose as involving different stakeholders can be time-consuming, especially in the case with many participants and conflicting opinions; and the resource availability – in terms of human capacity, including the facilitators who manages the participatory process, finances, and technical tools

6. Social and political context

Is there sufficient trust and cooperation among stakeholders to support decision making, and are vulnerable groups represented and included in the participatory process.

As we are not the decision maker in Glückstadt (DEM5), we applied this multi-criteria decision analysis with aim to support the decision maker with a recommendation. By implementing this process, we take all different views from the stakeholders, encourage stakeholders' commitment by giving them the chance to contribute and influence, provide useful additional information to the stakeholders, promote mutual learning and build trust among interested parties (Dean, 2021; Mustajoki et al., 2004). Moreover, as Hobbs and Meier (2012) argued, multi-criteria decision analysis improves the quality of the decision by evaluating risk and uncertainty and communicating the priorities by different stakeholders and focusing on the fundamental objectives.

4. Application in Demonstrator 5

In this task, we carried out the approach in a co-design manner by engaging municipality, citizens, critical infrastructure suppliers, and experts and co-identified that the Demonstrator 5 would like to focus on multiple objectives, but impacts are not quantifiable. Therefore, a stakeholder-led and qualitative multi-criteria analysis of DRR and CCA measures is carried out in Glückstadt, a city in Schleswig-Holstein, Germany (DEM5). We carried out a multi-criteria analysis with a participatory approach to engage different stakeholders, with the aim of using this approach to engage citizens and decision-makers in their decision-making on the implementation of DRR and CCA measures. With this approach, while conducting the analysis, we concurrently raise awareness of the multi-hazard risks in the city and help its inhabitants better prepare for extreme events.

4.1.1. Study area

Glückstadt is a city in Steinburg district of Schleswig-Holstein state, Germany. It is located along the northeast bank of Elbe River. According to the census done in 2022, Glückstadt's area comprises of 2274.85 ha with a total population of 10.987 people, comprises of several age groups: (Statistikamt Nord: Meine Region – Datenanzeige für Glückstadt, Stadt, n.d.)

- 14.5% aged 0-17 years
- 7.1% aged 18-24 years
- 5.7% aged 25-29 years
- 21.7% aged 30-49 years
- 25.7% aged 50-64 years and
- 25.4% aged 65 years and older

The populated area is protected from the Elbe River by the dike, which is managed by the Kremper Marsch and Wilstermarsch Dike and Main Drainage Association (Deich- und Hauptsielverbände Kremper Marsch und Wilstermarsch). Besides maintaining the dike, the Kremper Marsch and Wilstermarsch Dike and Main Drainage Association also manage the drainage system and pumping station operation in Glückstadt, which plays a role in the storm surge and flooding protection, especially considering the geographical location of Glückstadt.

4.1.2. Multi-risk in Glückstadt

As it is located along the Elbe River, Glückstadt is prone to coastal floods. The worst coastal floods happened in 1962 and 1976 with maximum height of the water level 5,6 m and 5,83 m respectively. Based on coastal flood map (2019) developed by Schleswig-Holstein state, only in the extreme scenarios in 200 years return period, the city of Glückstadt will be flooded, which means the current protection measures already exist and are able to prevent major impact on the city. However, in the case of extreme scenario with 200 years return period, where more than half of the city will be flooded with water depth more than 4 meter.

With the extreme wind velocity more likely to happen more often in the future, the risk of coastal flood also increases. Storm surge in Glückstadt usually happens when the wind creates a surge in the Elbe. If heavy precipitation happens at the same time in Glückstadt, inundation on land will happen because of the water pressure from the North Sea. As the climate model shows that the total amount of precipitation will increase up to 19.2% by the end of 2100, the risk of flash flood inundating the area of Glückstadt would also increase.



In general, people living close to the dike and in the low-lying areas are most at risk in the event of a storm surge (source). Moreover, based on census in 2022 (StatistikNord, 2022), more than half of the population of Glückstadt is in the age group 50-64 years old (25.7%) and 65 years old and older (25.4%), this elderly group is also taken into consideration of vulnerable groups. This also relates to the risk of heatwave, where the temperatures, the number of hot summer days and tropical nights, the length of heatwave, and the number of hot and humid days will increase in the future, and the vulnerable groups in the case of extreme heat include infants, children, pregnant women, and the elderly (UNICEF, n.d).

In previous events, there was no major damage in Glückstadt, as the storm surge only affected the outer harbour of the city. The immediate effects of the storm surge in Glückstadt include the disruption of the city's economic activities and the urgency of cleaning up the debris.

Besides the risk of storm surge, Glückstadt is also prone to flooding due to precipitation. During interviews with the stakeholders, we found out that in recent years, the basement of their house has been flooded when heavy precipitation occurs. The flooded basement may increase the development of mold which leads to other challenges, especially regarding the health of the residents.

The multiple and systemic risk of Demonstrator was presented and explained in the public event via the systemic risk propeller with exposure, hazard, vulnerability and response (Simpson et al., 2021). By applying the systemic risk framework in Demonstrator 5, the systemic risks identified are the several systemic risk scenarios: (1) Combination of heavy precipitations and high tides of Elbe River, with overflowing streams of water from Rhin and Stör rivers surrounding the city. The systemic risks across systems would be if this flooding scenario would happen in combination of electricity blackout; and at the same time, (2) heatwaves during summers will continue to impact older populations in Glückstadt, and how a climate risk would increase risks in disasters and health domains.

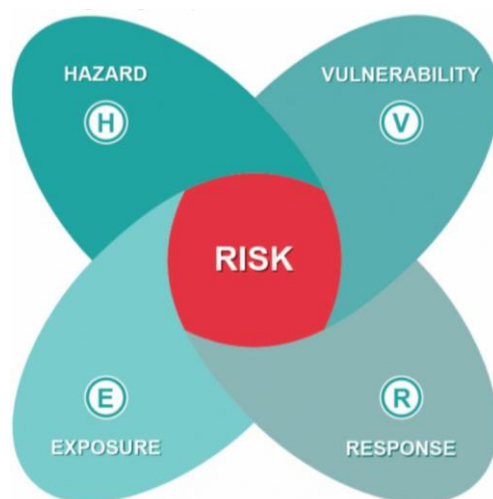


Figure 2: Systemic risk framework applied in the Demonstrator 5 (Source: Simpson et al., 2021).

4.1.3. Participatory Multi-criteria Analysis (MCA)

As part of the participatory process, we continuously interacted and engaged for input from different groups of stakeholders in Glückstadt. We started this process by looking through journal articles and newspaper articles to find out about the past events and current measures to deal with extreme events in Glückstadt. We then collected and evaluated the measures before conducting the analysis.

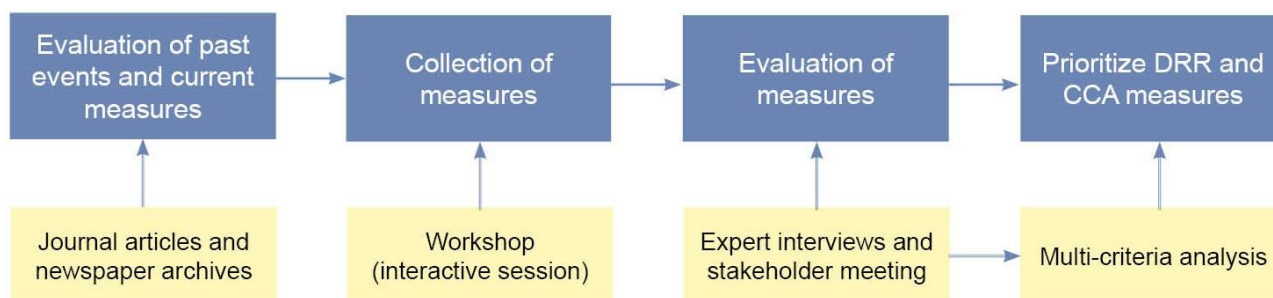


Figure 3: Methodology of this study.

The application in Glückstadt comprised a few steps.

STEP 1

We have conducted desktop research prior the co-design process with the stakeholders. The desktop research includes data from archives and flooding records from the state, district or city level. After our desktop research, a meeting with municipality with relevant decision-makers also took place to discuss and validate the desktop research outcome. The following table provides an overview of desktop research outcome.

Table 1: Past storm surge events.

Date	Impact
31 Jan 2013	Mean high tide in Glückstadt= 2,61m
6 Dec 2013	Mean high tide in Glückstadt= 3,73m
11 Jan 2015	Mean high tide in Glückstadt= 2,82m
30 Nov 2015	Mean high tide in Glückstadt= 2,50m
27 Dec 2016	Mean high tide in Glückstadt= 2,57m
07 Jan 2019	Water levels were expected to be over 1.5 meters above high water
8 Aug 2023	No major damage. Flooding in the outer harbour 1.45 m above regular water tide.

	The night before warning was issued by <i>Bundesamt für Seeschifffahrt und Hydrographie</i> - Federal Maritime and Hydrographic Agency (prediction of water level between 1 -1.5m). Debris and collapsed tree were cleared out by municipal service of the Glückstadt public utility company.
20 Oct 2023	<i>Extremely low water</i> Storm from the east pushed the water off west coast of Schleswig-Holstein (including outer harbour of Glückstadt), causing ships and ferries stopped operating.
22 Dec 2023	Alarm was triggered by rescue coordination center the night before because a car was seen at the outer harbour (due to almost 2 m high storm surge). Forecast: flood up to 3 m above normal. In the morning fire brigade and Glückstadt emergency services started working to remove large trees and clean the debris.

Table 1 indicated that the storm surge in Glückstadt impacts mostly on the outer harbour and not in the populated area. The storm surge warnings are usually issued by the Federal Maritime and Hydrographic Agency via radio or television and the warning app "NINA" when the water level is 1.50 m above the mean high tide. Cases where the water levels of +2.50 m above mean high tide can occur several times within a year, usually don't impact the city. However, if there is a warning issued of a very severe storm surge with a water level of +3.50 m or more, the residents and the first responders should start taking precautions, such as filling the sand sacks and putting manure as sealing material in the flood gate.

Regarding the coastal protection, due to the continuous monitoring and maintenance, Glückstadt is well prepared in medium term (until 2050) if the dike doesn't break. The challenge comes from the nutrias or in the cases when a few storm surges happen in a row and weaken the dike structure. It will also be challenging to predict what would happen in the long term (beyond 2050). However, to overcome this challenge, the Schleswig-Holstein state already started to take further steps to enhance the technical solutions of the dike system and integrate nature-based solutions to reduce the pressure of the surge.

The city of Glückstadt is not only prone to the coastal flooding, but also flood because of heavy precipitation. This type of flood usually impacts the buildings in the low-laying area, especially those with basement level. The waterlogging in the basement level happens more frequently in recent years and the residents already started to take some precautions, for example moving the electronic devices and furniture from the basement and searching for the proper individual flood gate to be used in their houses.

STEP 2.

Assessment of current measures in the city, past impacts and future risks.

In this step, we use the data on past disasters, current measures in place, and future risks from journal articles and newspaper archives to draw initial conclusions.

STEP 3.

Collection of DRR and CCA measures



During an interactive session at a public event, we asked the participants, who are residents of Glückstadt and currently work in the municipality, local associations and clubs, about their past experiences of dealing with multi-hazards in Glückstadt and future measures they would like to implement, or think would be beneficial to reduce the impact of multi-hazards in the city. The age range of the participants was between 39 and 71 years old. In addition, we have divided the measures into two categories: structural measures and non-structural measures.

Soft measures include:

- Increasing community preparedness by having more public communication about disaster and how to minimize the damage, education in school, consultation, emergency plan, improving self-awareness, more engagement in voluntary works, and helping each other
- Financial support, including storm surge insurance and funding for green roofs/facades and green building
- Improving the current system, such as the early warning system

Hard measures include:

- against storm surges, including improvements to the climate dike, maintenance of the drainage system, mobile pumps and sandbags
- against flooding, including maintenance of drainage systems, mobile pumps, household pumps, rainwater catchment basins, tree planting, green roofs and surface unsealing
- against heat waves, including planting trees, unsealing surfaces, installing green roofs, reactivating public water dispensers and providing shaded areas
- additional measures not directly related to disaster risk reduction and climate change adaptation, such as bicycle lanes, limiting the use of private cars in the city, train connections, electric car charging stations, and PV panels on new buildings

For further analysis, we narrow our scope to structural measures. We argue that non-structural measures should be implemented as a basis for reducing multi-hazard risks, thus we focus on the structural measures. The soft measures are collected for future stakeholder workshops for measures for implementation through citizen boards and list of recommendations for municipal decision-making.

STEP 4.

Evaluation of the measures.

After grouping the measures, we conducted expert interviews and a stakeholder meeting to determine the feasibility and effectiveness of the measures if they were to be implemented in Glückstadt. We asked a total of 17 people from different stakeholder groups. In addition to evaluating the measures, we used the input from the expert interviews and stakeholder meeting as the basis for a multi-criteria analysis.

Through the transparent and open process, a series of co-design processes and activities have been carried out through the process, among them, 3 public events has been launched (city district festival in 2023, and 2024 (visitors roughly 150 participants, the intense interaction with roughly 25 participants each), and two public events with dedicated stakeholder workshops with more than 120 participants (citizens, experts, group representatives, etc.). Additionally, a series of stakeholders interviews and additional meetings with experts and stakeholder groups have been carried out. The list of stakeholders include:



Table 2: List of stakeholder groups with their function in Glückstadt.

Person	Stakeholder group	Function in DRR and CCA implementation in Glückstadt
1	Dike and main drainage association	Responsible for the construction, operation, and maintenance of drainage system, including maintaining the dike, water course, and pumping stations.
2	Wastewater association	Manages and monitors the drainage (pumping) system and safe wastewater and stormwater disposal
3	Wastewater association	
4	City administration	Responsible for the policy implementation and manages the operation of daily activities in the city
5	City administration	
6	Local organization	Helps the integration of people with migration background in the city; gives input from vulnerable group
7	First responder or volunteer	The first responders or volunteers usually work before and after the extreme events, including preparing the sand sacks and cleaning the debris in the outer harbor and the streets
8	First responder or volunteer	
9	First responder or volunteer	
10	First responder or volunteer	
11	Private entity	Business owners in Glückstadt, comprise of sustainability consultant, contractors, and other small and medium enterprises (e.g. relevant private sectors such as water damage restoration after flooding damages). This stakeholder group plays a role in preparing the city to be more resilient in the case of extreme events, including providing more opportunities of economic activities (practical examples are cleaning and draining flood water from the basement, repairing the house element when needed)
12	Private entity	
13	Private entity	
14	Private entity	
15	Private entity	
16	Citizen	Residents living in Glückstadt who have experienced previous extreme events and invested or paid for damages or measures giving input from local perception and experience (including cost and benefits of the measures)
17	Citizen	

STEP 5.

Multi criteria analysis

The steps of the multi-criteria analysis in this study adapt Saaty's Analytical Hierarchy Process (1990, 2008) with some adjustments to include the participatory process. The steps of the analysis include:



5.1. Define objective

Objective: To identify and prioritise DRR and CCA measures in Glückstadt to address storm surge, flooding and heat waves.

5.2. Structure criteria, sub-criteria, and measures considered

Criteria: effectiveness, affordability, economic, and equitability

Sub-criteria:

Alternatives or DRR and CCA measures considered:

1. Improving climate dike (Klimadeich – a type of dike) addressing storm surge
2. Maintaining drainage system addressing storm surge and flooding
3. Mobile pump addressing storm surge and flooding
4. Sandsacks addressing storm surge
5. Pump at household addressing flooding
6. Rainwater catchment basin addressing flooding
7. Tree planting addressing flooding and heatwave
8. Green roof addressing flooding and heatwave
9. Surface unsealing addressing flooding and heatwave
10. Reactivation of water fountain addressing heatwave
11. Shaded place addressing heatwave

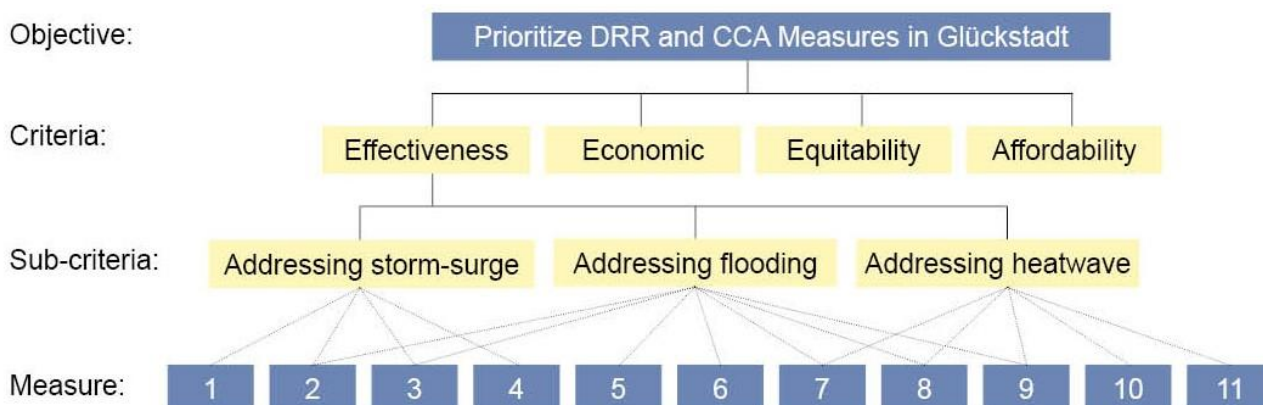


Figure 4: Structure of objective, criteria, and sub-criteria.

5.3. Weighting criteria and sub-criteria

In the Analytical Hierarchy Process, a pairwise comparison is made to determine the weight of each criterion by comparing the importance of the criteria. In the application in DEM 5, we tried to explore the perceptions of different stakeholder groups by asking them to rank the criteria in order of importance when identifying and prioritising DRR and CCA measures in a city. In this way, we can verify their views on the four criteria, rather than just reach a

consensus on which criterion is the most important. The pre-selected criteria are effectiveness, economics, equity and affordability. The criteria of effectiveness, economic, equitability, and affordability are selected to ensure justice and fairness principles beyond cost and benefits (Fletcher et al., 2016). The selection of the criteria has a certain degree of freedom as long as it has a solid scientific reasoning (for instance, based on literature or previous practical experience), and inclusive engagement from the stakeholders. In the Demonstrator of Glückstadt, the criteria is chosen based on a similar setting of a coastal climate change adaptation case (Fletcher et al., 2016), where the criteria of economic, equitability and affordability could serve an important role in leading discussing with decision-makers in coastal municipalities: (1) when the measures are economic and affordable, it make sense for private households to implement them as low-regret and win-win measures; when the measures are economic and equitable but not necessarily affordable, it make sense to discuss the state-level or municipal level responsible for investing the measures. These criteria are therefore very relevant in the setting of the Demonstrator, Glückstadt, and it makes sense to implement them. Additionally, we presented these measures and discussed with the stakeholders and experts, and obtained the feedback that the measures have to also be effective (from stakeholders' experience and evaluation). Therefore, at the end, four criteria of effectiveness, economic, equitability and affordability were selected.

- Effectiveness means the capacity of the option or strategy to achieve the intended effect of reducing the impact of extreme events in the future.
- Economic means providing benefits to all stakeholders in the city in terms of reduced losses due to extreme events.
- Equitability means the fair and equitable distribution of benefits and costs of measures among residents
- Affordability means that the measure can be afforded by the community

The result of the ranking of the criteria is shown in Table 3. The table shows that, in terms of importance, effectiveness is the highest priority or most important, followed by economics in second rank, affordability in third, and equitability as the least important of the preselected criteria.

In identifying how many times more important one criterion is than the others, we analysed the responses from different stakeholders using Mean Reciprocal Rank, a statistical method where the weight is given from the multiplicative inverse of the rank, rather than using the pairwise comparison. This means that for the most important criteria (1st rank) the weight is 1, for the second rank $\frac{1}{2}$, for the third rank $\frac{1}{3}$ and for the last or least important criterion $\frac{1}{4}$. The aim is to take into account each stakeholder's input on the importance of the criteria.

Table 3: Input from stakeholder regarding criteria ranking based on its importance.

Person	Effectivity		Economic		Equitability		Affordability	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score
Person 1	1	1	2	1/2	3	1/3	4	1/4
Person 2	1	1	2	1/2	3	1/3	4	1/4
Person 3	1	1	2	1/2	3	1/3	4	1/4
Person 4	1	1	2	1/2	3	1/3	4	1/4
Person 5	2	1/2	1	1	3	1/3	4	1/4
Person 6	1	1	4	1/4	2	1/2	3	1/3



Person 7	1	1	3	1/3	2	1/2	4	1/4
Person 8	1	1	2	1/2	3	1/3	4	1/4
Person 9	1	1	2	1/2	4	1/4	3	1/3
Person 10	1	1	4	1/4	2	1/2	3	1/3
Person 11	2	1/2	1	1	3	1/3	4	1/4
Person 12	1	1	4	1/4	3	1/3	2	1/2
Person 13	1	1	3	1/3	4	1/4	2	1/2
Person 14	1	1	4	1/4	2	1/2	3	1/3
Person 15	2	1/2	4	1/4	3	1/3	1	1
Person 16	2	1/2	4	1/4	3	1/3	1	1
Person 17	-	-	-	-	-	-	-	-
Total score	14	7.16	5.8	6.32				

Thus, the weight for effectivity = $14/33.28 = 0.42$

Weight for economic = $7.16/33.28 = 0.22$

Weight for equitability = $5.8/33.28 = 0.17$

Weight for affordability = $6.32/33.28 = 0.19$

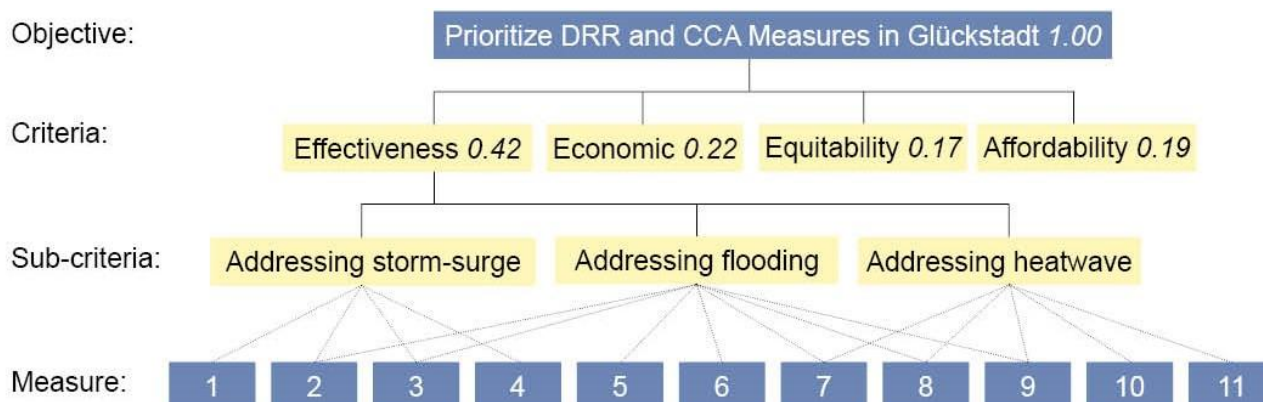


Figure 5: Input from stakeholder regarding criteria ranking based on its importance.

The next step is to weight the sub-criteria. The weighting of the effectiveness criterion is divided into 3 groups according to the effectiveness of the DRR and CCA measure in addressing storm surge, flooding, and heatwaves. The weighting is based on a qualitative assessment to estimate the risk which is gathered from expert interviews. The scoring is done by assigning a simple score based on the likelihood of its occurrence and the severity of the impact (Graves, 2000). The scoring includes low likelihood or impact (score = 1), medium likelihood or impact (score = 2), and high likelihood and impact (score = 3). The final score is derived from multiplying the score of likelihood and impact.

- Storm surge = likelihood = medium (score = 2), as the future climate change projection shows that extreme wind velocity will occur more often (Pfeifer, Bathiany, and Rechid, 2021). Impact = medium (score = 2). The storm surge protection measure

is already in place and is continuously monitored online and inspected on site once a week.

- Flooding: likelihood (3) high, as many residents said that in recent years the basement of their house is often flooded during heavy rainfall, and that this is happening more often and with greater intensity. Impact = medium (2), as many elderly people live in houses with cellars, and they are constantly trying to find a solution to this problem.
- Heatwave: likelihood = high (score = 3), considering that the residents who participated in the workshops and interviews agreed that they feel that heat days have become more frequent and intense in recent years. Impact = medium (score = 2), considering that most people already start thinking about the impact of a heatwave and starting to prepare the measure that they can do to minimize the risk.

To summarize, the weight of sub-criteria:

$$\text{Risk} = \text{likelihood} \times \text{impact}$$

Thus, storm surge risk: $2 \times 2 = 4$

Flooding risk: $3 \times 2 = 6$

Heatwave risk: $3 \times 2 = 6$

Weight of effectivity = 0.42

Effectivity related to storm surge: $4/16 \times 0.42 = 0.1$

Effectivity related to flooding: $6/16 \times 0.42 = 0.16$

Effectivity related to heatwave: $6/16 \times 0.42 = 0.16$

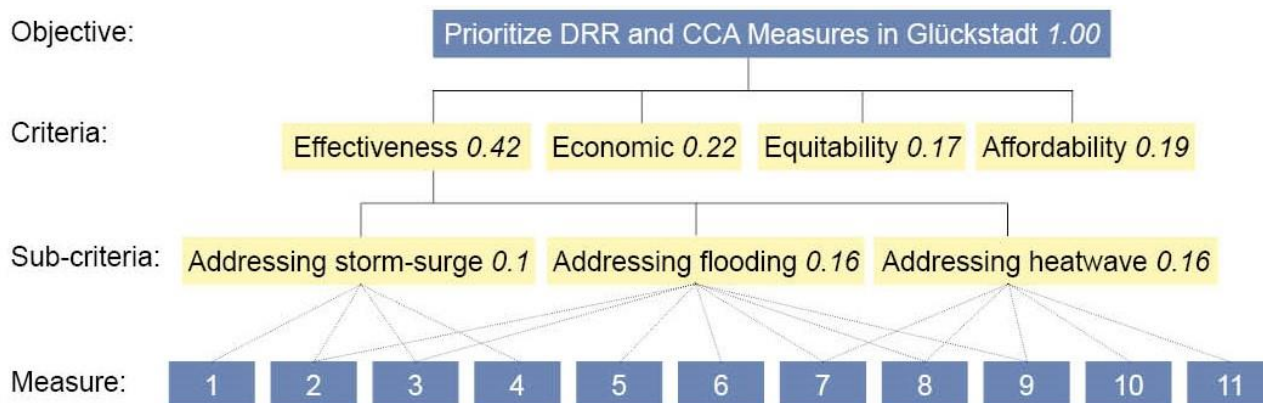


Figure 6: Input from stakeholder regarding sub-criteria ranking based on its importance.

5.4. Calculate performance of the measures against criteria

This step involves comparing how well each measure performs with respect to each criterion. Stakeholders were asked to give their input on the performance of the measures against the four criteria by assigning scores of completely disagree, disagree, agree and completely agree. Furthermore, completely disagree is given a score of 1, disagree is given a score of 2, agree is given a score of 3 and completely agree is given a score of 4. This means that the higher the score, the better the measures perform in relation to the four pre-selected criteria.

The first measure, improving the climate dike, when we asked the stakeholders whether improving the climate dike is effective in reducing the impact of storm surge in the future, no one chose 'completely disagree', 1 person chose 'disagree', 6 people chose 'agree', 9 people chose 'completely agree', and 1 person chose 'I don't know'. Therefore, to calculate the performance of climate dike in term of effectiveness criterion: $(0 \times 1) + (1 \times 2) + (6 \times 3) + (9 \times 4) + (1 \times 0) = 56$. This step to calculate the performance of the measures is done for all criteria and all measures.

The complete result can be seen in Annex 1.

Table 4: Performance of the measures.

Measure	Criteria	Completely disagree (score = 1)	Disagree (score = 2)	Agree (score = 3)	Completely agree (score = 4)	I don't know (score = 0)	Total score
Improving climate dike	Effectiveness	0	1	6	9	1	56 (a)
	Economic	0	1	6	9	1	56 (b)
	Equitability	0	0	2	9	6	42 (c)
	Affordability	0	0	7	10	0	61 (d)
Drainage system	Effectiveness	1	2	4	7	3	45
	Economic	0	3	4	6	4	42
	Equitability	1	1	7	4	4	40
	Affordability	2	1	6	5	3	42
To be continued for all measures							

5.5. Get the ranking of the measures

This involves combining the criteria weights with the performance scores for all the measures to produce an overall ranking of the measures. The criterion weight is derived from step 5.3 and the performance score is derived from step 5.4.

The first measure, improving the climate dike, is a measure against storm surge, and not against flooding and heatwaves. Therefore, the performance score of effectiveness criterion for 'improving climate dike' (score = 56, derived from (a) in Table 4) is entered in the second column 'storm surge' and not in the column 'flood' and 'heatwave'. The performance score of economic criterion for 'improving climate dike' is derived from (b); the performance score of equitability criterion for 'improving climate dike' is derived from (c), and the performance score of affordability criterion for 'improving climate dike' is derived from (d). The higher the weighted score, the better the performance of the measure in relation to all criteria. This step is performed for all measures to obtain the ranking of the measures.

Table 5: Weighted scoring of the measures.

Measure	Effectiveness (0.42)			Economic (0.22)	Equit-ability (0.17)	Afford-ability (0.19)	Weighted Scoring	Rank
	Storm surge (0.1)	Flood (0.16)	Heat-wave (0.16)					
Improving climate dike	To be filled from (a) from Table 2			(b)	(c)	(d)		
	56	0	0	56	42	61	36.65	3
Drainage system	45	45	0	42	40	42	35.72	4
Mobile pump	39	39	0	35	35	47	33.16	7
Sand sack	52	0	0	53	39	58	34.51	6
Pump at household	0	46	0	45	30	47	31.29	9
Rainwater catchment system	0	59	0	52	31	35	32.80	8
Planting tree	0	47	47	58	37	51	43.78	1
Green roof	0	51	51	39	25	34	35.61	5
Surface unsealing	0	54	54	47	35	43	41.74	2
Reactivation of public water dispenser	0	0	39	33	31	48	27.89	10
Shaded place	0	0	20	18	16	48	19.00	11

The results are shown in Table 5. It demonstrates that from the list of measures, different stakeholder groups ranked and prioritized planting trees, surface unsealing, and improving climate dike as priority measures. The results do not mean the finalized results which the municipality or citizens are binding to implement, but to serve as a decision-making support tool for discussing priorities, and objectives and criteria different vulnerable groups prioritize measures. Most importantly, applying the fairness, affordability, effectiveness and equitability objectives stimulate discussions and provide decision-making support systems to prioritize them according to resources for implementation at different levels (individual, household, community, city, district, state levels).

4.2. Validation with the stakeholders and decision-makers

During the interviews, the DRR and CCA measures presented were partially validated by the decision-makers and technical experts.

The most important validations of the measures presented and assessed in connection with the weather extremes prevailing in Demonstrator 5 are listed below:

- (1) Measures targeting on storm surge and inland flooding due to continuous precipitation are satisfactory for existing conditions, but for future risk, especially under systemic risk, would need more closer examination.

- (2) Rainwater catchment basins are a good measure in principle, but in the specific case of the Itzehoe hospital (City in the district of Steinburg), where a new rainwater catchment system has been built, it has not yet stored any water, so it has to be operated manually.
- (3) Measure targeting on the tree planting: Decision-makers validated tree planting, taking into account specific tree species, as the first priority measure, as these are low-hanging fruits in terms of additional budgets.
- (4) The list of measures corresponds to the multiple authorities and areas of responsibility: Both the political decision-makers and the technical experts repeatedly emphasised the multiple layers of authority and responsibilities in DRR and management. For example, storm surges are the responsibility of the state of Schleswig-Holstein, i.e. dikes including the climate dike are managed by the state. Along the west coast of Schleswig-Holstein, there is a so-called priority list, where the state decides which sections of the dike need to be reinforced in the future and where the building of the climate dike is approved. These are reasons why the implementation of a future climate dike in Glückstadt is a lengthy process.
- (5) The measures are results of close cooperation with the dike and drainage association: The city council manages, monitors closely with the dike and drainage association to ensure state of the art to prevent flooding during precipitation and a well-functioning digital and analogue channel monitoring system.
- (6) The measures present conflicts of interest between nature and engineering solutions: Building a climate dike in the Wadden Sea conflicts with the World Heritage Act. Urban planners clash with rainwater retention basins.
- (7) Continuous open process: This participatory multi-criteria analysis is an open process whose main objective is to increase the city's resilience to extreme events, taking into account the priorities of the various stakeholders. We will therefore continue to develop the discussion thread with the stakeholders and possibly come up with new validations and maybe initiate new formats, such as the introduction of a well-positioned climate council.

5. Insights and lessons learned

5.1. Participatory MCA for supporting decision-making

The participatory approach is key to this stakeholder-led multi-criteria analysis. As part of an ongoing process of co-design approaches, we have conducted expert interviews and panel meetings, stakeholder workshops and public events. At these events several suggestions were collected from citizens, expert panels and members of the public.

The list of ideas includes displaying information boards in public places about local climate extremes and how to prepare for them.

Furthermore, the establishment of a climate council within the city, composed of citizens and key experts (first responders, critical infrastructure providers, etc.), to ensure robust implementation and decision-making for integrated DRR and CCA measures on an ongoing basis.

In general, it can be said that everyone involved in the participatory MCA was highly motivated to be kept up to date and "stay on the ball".

These outcomes showcase the potential of a participatory approach of MCA, which could be a driver for its implementation at demonstrator level.

5.2. Innovations: strengths and weaknesses

The participatory multi-criteria analysis can be used as a tool to start a dialogue between representatives of different groups or parties in order to improve the preparedness for extreme events in a city. During the participatory process in the DEM5 application, we found that citizens start to think about what they have done and what they can do in the future to better protect themselves and minimise the impact of extreme events. In addition, more local knowledge can be gathered and more representatives from different parties can be involved in transforming their city into a 'safe haven'.

Another advantage of this method is that this process can be carried out regularly in the future, using this report as a basis for improving DRR and CCA measures in Glückstadt. In the application in DEM 5 we tried to involve the vulnerable groups in the city, for example the elderly and people with a migration background. Not all efforts were successful, but this process can be a starting point for involving more people from different backgrounds or groups.

Finally, participatory multi-criteria analysis can be carried out with limited technical resources. This leads to a higher chance of transferability when implemented in another area with different local contexts. However, similar to other participatory processes, it can lead to subjective results depending on the stakeholders involved in the process. It is important to ensure that not only one or two parties are involved, but that a wider range of stakeholders represent their perspectives.

5.3. Limitations and outlook

In terms of limitations for future applications of participatory multi-criteria analysis, it would require further analysis if the measures were taken by citizens only, for example the different levels of



awareness and knowledge of different stakeholder groups. However, this challenge can be overcome through knowledge transfer or public information events.

Mention sensitivity analysis and robustness analysis to be carried out later for journal publication, our argument that we prioritised for transformation and implementation for the first 24 months of the project.



6. Further applications and transferability

To accelerate the implementation and transferability of participatory MCA to further Demonstrators, and as to achieve the KPI and expected outcomes in The HuT, we have identified different transferable settings according to the potentially matching Demonstrators without binding. In the following table we show the overview of possible transferability of participatory MCA to further Demonstrators within and beyond The HuT.

No.	Systemic risks	Possible required data	Approaches recommended	Way forward
1	Heatwaves and health impacts	Quantitative data (open data) used in the droughts and heatwave analysis	Cost-benefit analysis	Contact Dem1 (Spain/Valencia) for applying this approach. Further identify transferrable Demonstrators and beyond with Dem 1
2	Heavy precipitation and street flooding	Quantifying data obtained from civil Protection agency/its regional branch and Lithuanian agency of hydrometeorology	Cost-effectiveness analysis	Contact Dem 4 (Lithuania/Vilnius) Seek for further scalability to Dem 2 and Dem 3
3	Plural floods under climate extremes	A set of existing measures have been identified: VÍZ24 mobile application, plans, maps and an alarm system	Participatory multi-criteria analysis	Contact Dem 7 (Hungary/Tisza) to gather experts input for evaluate the effectiveness of the measures (and include further criteria and objectives)
4	Preparedness for systemic risks of hydrometeorological events	Use the existing data to estimate possible costs and benefits / effectiveness of existing measures	A mix of quantitative and qualitative approaches	Contact Dem 6, 8, 9, 10 to use existing data (for insurance, qualitative input from stakeholders) to estimate and evaluate outcomes of the existing preparedness measures

This strongly stakeholder-driven method has the potential to be transferred to other regions with a different set of hazards. Moreover, it is not based on models and therefore does not require modelling skills. Technical data from experts does not necessarily have to be requested. This qualitative MCA is essentially and deliberately focused on stakeholder input, which does not exclude the possibility of feeding technical data to this MCA in a further follow-up.

After submitting D.3.4, it is intended that the participatory MCA will be carried out in three further Demonstrators, as agreed by The HuT coordinators at the consortium meeting in 2024, these are Demonstrator 1 (Spain/Valencia), Demonstrator 4 (Lithuania/Vilnius) and Demonstrator 7 (Hungary/Tisza). In addition, Demonstrator 4 (Vilnius) requested the interview questions applied within our MCA.

Even if no further deliverables in this regard are sought, we will make this method available to the DEMs concerned.



7. Action plans

Building on the experience gained from implementing the participatory MCA approach in DEM5, this section outlines action plans for adopting this methodology to address other systemic risks identified in various DEMs. The lessons learned from DEM5 underscore the significance of stakeholder inclusion, transparency, and the integration of diverse data sources. The participatory MCA's simplicity and low resource demands make it highly transferable to regions facing different systemic risks, as it does not necessitate advanced technical modeling while still allowing for the incorporation of relevant technical data when necessary.

The activities outlined in the following action plans are designed to address specific systemic risks, including heatwaves, urban flooding, plural floods, and preparedness for hydrometeorological events across multiple contexts. Each plan draws from the insights gained in DEM5 and considers the contextual differences among the demonstrators. By focusing on common strategies that can be scaled and adapted, these action plans aim to facilitate effective implementation of participatory MCA in diverse settings. The activities are proposed as ideas rather than mandate to mainly initiate discussions to kick-start this activity in demonstrators by exploiting existing ongoing activities of demonstrators. The criteria proposed in each of the demonstrators are firstly following the same criteria implemented in demonstrator 5 because it makes it easy to understand the concept of choosing criteria in MCDA by comparison. However, each demonstrator has complete freedom to select their own method and criteria.

Additionally, at the end of the implementation phase in the Demonstrator 5, an open-access tool on multi-criteria decision analysis (MCDA) has been developed. This tool allows stakeholder engagement in the MCDA process. It not only makes MCDA participatory, but it will also make analysis easier by allowing different demonstrators to choose the wished aggregation methods, and to visualisation.

A useful toolbox:

HELDA: An Open-Access MCDA Tool for Demonstrators

The HELDA software, developed by the Helmholtz Association, is an open-access multi-criteria decision analysis (MCDA) tool specifically designed to aid decision-making in sustainability, disaster risk reduction, and climate adaptation scenarios. HELDA offers a suite of aggregation methods, such as TOPSIS and PROMETHEE, and provides weighting tools including AHP and SMART, allowing tailored, data-informed assessments. It supports sensitivity and uncertainty analyses, offers robust visualization options, and includes an interactive stakeholder plugin, enhancing collaborative decision-making (HELDA, Version 1.0, 2024). We highly recommend the demonstrators to use this tool and please find the open-access MCDA tools here: <https://www.mcda-helmholtz.de/64.php>

7.1. Action plan for systemic risk: heatwaves and health impacts (DEM1 Valencia, Spain)

Stakeholder engagement

Objective: To identify key stakeholders and ensure their active involvement in the decision-making process aimed at mitigating heatwave risks and health impacts in Valencia.

Activities:

1) Use of existing quantitative data:

Demonstrator 1 has a team of applying different quantitative methods (e.g. system dynamics, quantitative modelling, etc.) and this would be a good basis for the cost-benefit analysis if quantitative data for cost and prevented damage costs related to heatwave risks and health impacts are available. If not all quantitative data are available, the following activities are proposed.

2) Initial Workshops:

Organization of a series of workshops involving local health authorities, urban planners, climate experts, and community representatives. These workshops will serve as a platform to discuss the specific risks associated with heatwaves, share experiences, and collaboratively identify potential adaptation measures. The focus will be on understanding the unique challenges faced by different community segments during heat events.

3) Delphi Method for Expert Consensus:

Use of the Delphi method to gather insights from climate scientists and public health experts regarding heatwave risk projections and intervention strategies. This iterative process will involve multiple rounds of questioning to refine expert opinions and achieve a consensus on the most effective measures to address heatwave impacts.

4) Engagement of Vulnerable Groups:

Representatives from vulnerable populations should be actively included, such as the elderly, low-income households, and outdoor workers, in the stakeholder engagement process. This will ensure that their specific needs and concerns are addressed in the decision-making framework, promoting equity and inclusiveness in developing heatwave response strategies. The experience from DEM5 highlighted the critical importance of including vulnerable groups in stakeholder engagement efforts. Their perspectives not only enrich the decision-making process but also help ensure that interventions are equitable and effective. This approach should be replicated across all DEMs to foster community resilience against heatwaves.

Transfer of Lessons Learned from DEM5

- **Vulnerable Group Inclusion:** Building on DEM5's success in engaging vulnerable groups, workshops will prioritize these groups in Valencia to ensure the proposed measures address their specific needs.
- **Deliberative Sessions:** Replicating DEM5's approach, these sessions will facilitate open discussions on personal experiences and community concerns about heat impacts, ensuring social acceptability and broader community support.



- Preventative Training: Include training modules on actions to mitigate heat risks, such as hydration, proper ventilation, and the use of designated cooling areas, particularly targeting vulnerable community members.

Development of evaluation criteria

Objective: To establish evaluation criteria specifically tailored to Valencia's context, focusing on mitigating heatwave impacts and protecting public health.

Activities:

1) Criteria Identification:

Collaboration with stakeholders to define key evaluation criteria that will guide the assessment of proposed interventions. The criteria can include:

- Effectiveness: Measured by the reduction in heat-related illnesses and mortality rates.
- Cost-effectiveness: Evaluating the financial feasibility of proposed interventions, such as urban greening initiatives and cooling shelters.
- Equity: Ensuring that interventions adequately protect vulnerable populations, including the elderly and low-income households.
- Environmental Co-benefits: Assessing the potential for reducing the urban heat island effect and improving air quality.

2) Workshop for final criteria definition:

Organization of a follow-up workshop with key stakeholders to finalize the evaluation criteria based on consensus. This collaborative approach will ensure that all relevant perspectives are considered, leading to a robust set of criteria.

Identification of potential measures

Objective: To identify and prioritize potential heatwave mitigation measures tailored to Valencia's urban environment.

Activities:

1) Urban Greening Initiatives:

Exploring of options to create green corridors, pocket parks, and green roofs. These initiatives aim to reduce urban heat by increasing vegetation cover, which can lower surface temperatures and improve air quality.

2) Building Retrofitting:

Consideration of retrofitting existing buildings with cool roofs and improved insulation, particularly in vulnerable areas. These upgrades can help maintain cooler indoor temperatures during heatwaves, thereby protecting public health.

3) Cooling Infrastructure:

Identification of public cooling spaces such as cooling centers and misting stations. These facilities will provide relief for residents during extreme heat events, ensuring accessible areas where people can stay cool.

4) Early Warning Systems:



Strengthen public health communication strategies and develop early warning systems specifically for heatwaves. Effective communication will ensure that residents are informed about upcoming heat events and know how to protect themselves.

Evaluation process

Objective: Use participatory Multi-Criteria Analysis (MCA) to evaluate and prioritize heatwave adaptation measures.

Activities:

1) Participatory MCA Sessions:

Organization of workshops with stakeholders to apply the MCA process. During these sessions, participants will evaluate the identified heatwave adaptation measures using the agreed-upon criteria. This collaborative approach ensures that diverse perspectives are considered in the assessment.

2) Pairwise Comparison:

Application of the pairwise comparison method to determine the relative importance of each criterion. This technique, based on Saaty's Analytical Hierarchy Process (2008), allows stakeholders to compare criteria directly, resulting in a clear hierarchy of priorities.

3) Scoring Measures:

Evaluation of each proposed measure using a combination of expert judgment and available data. Scoring will consider factors such as:

- Potential reduction in heat-related illnesses
- Implementation costs
- Feasibility within Valencia's urban context
- Long-term sustainability

Integration of Complementary Analyses

Objective: To complement the MCA with economic analysis (CBA and CEA) to provide a more robust decision-making framework.

Activities:

1) Cost-Benefit Analysis (CBA):

Application of a CBA analysis to quantify the economic benefits of selected measures. This analysis will focus on:

- Reduced healthcare costs due to decreased heat-related illnesses
- Energy savings from interventions like cool roofs
- Potential economic benefits from increased green spaces (e.g., property value increases)

Monitoring and Sensitivity Analysis

Objective: To ensure that chosen heatwave interventions remain effective under different future scenarios and stakeholder preferences.



Activities:

- 1) System for tracking the performance of implemented measures. This system can include:
 - a. Regular collection of data on heat-related health impacts
 - b. Monitoring of urban temperatures in areas with and without interventions
 - c. Surveys to assess public perception and use of adaptation measures
 - d. Periodic reviews (e.g., annually) to evaluate the effectiveness of implemented strategies.

These activities require the collaboration with local health and environmental agencies to collect data regularly on public health, urban temperatures and cooling infrastructure. Evaluations can be conducted every six months to assess the impact of the measures that were implemented.

Key metrics to be considered:

- a. Public health indicators: Track cases of heat-related illnesses recorded in health centers before and after the interventions.
- b. Urban temperature monitoring: Monitor temperature changes in areas with implemented cooling measures (e.g., green zones) compared to non-intervention areas.
- c. Cooling infrastructure usage: Measure the number of people using cooling centers and shaded areas through surveys and direct counts.
- d. Community satisfaction: Periodic surveys to assess public perception and satisfaction with the measures in place.

Summary of outcomes

- **Stakeholder Engagement:** Full involvement of diverse stakeholders, including vulnerable groups.
- **Context-Specific Criteria:** Evaluation criteria tailored to Valencia's specific climate and urban context.
- **List of Adaptation Measures:** A prioritized list of measures to mitigate the health impacts of heatwaves.
- **Comprehensive Evaluation:** Integration of participatory MCA with CBA for a balanced decision-making process.
- **Monitoring and Adaptability:** A plan for continuous monitoring and flexibility to adjust interventions as new data becomes available.

7.2. Action plan for systemic risk: intense precipitation and urban flooding (DEM 4 Lithuania, Vilnius)

Stakeholder engagement

Objective: To engage key stakeholders in the decision-making process to mitigate urban flood risks.

Activities:

- 1) Initial Workshops:



Organization of workshops with local water management authorities, urban planners, community representatives, and climate experts. These workshops will help identify specific risks and potential adaptation measures, focusing on the most vulnerable areas of the city.

2) Delphi Method for Expert Consensus:

Use the Delphi method to gather insights from hydrology and urban planning experts regarding risk projections and intervention strategies.

3) Engagement of Vulnerable Groups:

Inclusion of flood-prone neighborhoods and low-income residents, in the decision-making process to ensure their concerns are addressed.

Transfer of Lessons Learned from DEM5

- Participatory Engagement Model: DEM5's participatory approach can be adapted to Vilnius by emphasizing inclusive planning and regular engagement. Workshops and collaborative sessions will give residents and local authorities a role in defining solutions.
- Knowledge Transfer for Structural Preparedness: DEM5's focus on structural interventions can be adapted by informing Vilnius stakeholders about building modifications and other infrastructure changes for flood resilience.

Development of evaluation criteria

Objective: To establish evaluation criteria specific to the context of Vilnius, focused on mitigating urban flooding.

Activities:

1) Criteria Identification:

Collaboration with stakeholders to define key evaluation criteria, such as effectiveness (reduction of flood-prone areas), economic feasibility, environmental co-benefits, and equity.

2) Final criteria definition Workshop:

Organization of a workshop to finalize the evaluation criteria based on consensus.

Identification of potential measures

Objective: To identify and prioritize flood mitigation measures.

Activities:

1) Green Infrastructure Initiatives:

Consideration of options such as rain gardens and permeable pavements.

2) Improved Drainage System:

Consideration of upgrades to the drainage network and the creation of water retention areas.

3) Warning Systems:

Definition of an early warning system for multi-hazard events. Or, upgrading the ones that already exist if necessary.

Evaluation process

Objective: Use Participatory MCA to evaluate and prioritize urban flood adaptation measures.

Activities:

1) Participatory MCA Sessions:

Organization of a series of workshops with stakeholders to apply the MCA process. Participants will evaluate adaptation measures using the agreed-upon criteria.

2) Pairwise Comparison:

Application of a pairwise comparison method to determine the relative importance of each criterion.

3) Scoring Measures:

Evaluation of each proposed measure using expert judgment and available data.

Integration of Complementary Analyses

Objective: To complement MCA with economic analyses for a more robust decision-making framework.

Activities:

1) Cost-Effectiveness Analysis (CEA): Application of a CEA analysis to compare interventions that achieve similar outcomes but have different costs.

CEA findings will guide stakeholders in selecting the most cost-effective interventions for flood resilience in high-risk areas.

Monitoring and Sensitivity Analysis

Objective: Establish a continuous monitoring system to assess intervention effectiveness and adaptability.

Activities:

1) Regular Data Collection: Collaborate with local agencies to collect data on precipitation patterns, flood incidents, and the performance of drainage systems.

2) Semiannual Reviews: Conduct semiannual evaluations to assess the performance of measures and adjust interventions as necessary.

Summary of outcomes

- **Stakeholder Engagement:** Full participation of diverse stakeholders, including vulnerable groups.
- **Context-Specific Criteria:** Evaluation criteria tailored specifically to Vilnius's context.
- **List of Adaptation Measures:** A prioritized list of measures to mitigate urban flood impacts.
- **Comprehensive Evaluation:** Integration of participatory MCA with CBA and CEA for balanced decision-making.



- **Monitoring and Adaptability:** A plan for continuous monitoring and flexibility to adjust interventions as new data becomes available.

7.3. Action plan for systemic risk: multiple flooding under climate extremes (DEM 7 Hungary/Tisza)

Stakeholder engagement

Objective: To engage stakeholders, including cross-border actors, to address complex flooding.

Activities:

1) Regional Workshops:

Contact and gather representatives from water management, agriculture, local communities, and cross-border partners to identify flood management measures.

2) Delphi Method for Regional Consensus:

Use of the Delphi method to reach consensus on intervention strategies at the regional level.

Evaluation process

Objective: Use participatory MCA to evaluate and prioritize flood adaptation measures.

Activities:

1) Participatory MCA Sessions:

Organization of a series workshops with stakeholders to apply the MCA process.

2) Pairwise Comparison:

Application of a pairwise comparison method to determine the importance of each criterion.

3) Scoring Measures:

Evaluation of each proposed measure using expert judgment and available data.

Summary of outcomes

- **Stakeholder Engagement:** Participation from regional and cross-border actors.
- **Context-Specific Criteria:** Evaluation criteria tailored to the Tisza region.
- **List of Adaptation Measures:** A prioritized list of measures to mitigate multiple flood impacts.
- **Monitoring and Adaptability:** A plan for monitoring and adjusting interventions based on new data and conditions.

7.4. Action plan for systemic risk: Preparedness for systemic risk of hydrometeorological events

Stakeholder engagement

Objective: To ensure effective preparedness for hydrometeorological events across local contexts.



Activities:

1) Community Preparedness Workshops:

Engaging local governments, emergency services, community organizations, and residents to identify and evaluate preparedness measures.

2) Delphi Method for Consensus on Preparedness:

Contact and gather expert consensus on the most effective preparedness measures for each local context.

Development of Evaluation Criteria

Objective: To establish evaluation criteria for preparedness and response capacity.

Activities:

1) Criteria Definition:

Definition of criteria such as preparedness capacity, cost-effectiveness, and public perception.

2) Final Criteria Definition Workshop:

Organization of a series of workshops to reach a consensus on the evaluation criteria.

Identification of Potential Measures

Objective: To identify and prioritize preparedness measures for hydrometeorological events.

Activities:

1) Response Infrastructure and Early Warning Systems:

Evaluation of necessary infrastructure and early warning systems.

2) Community Training Programs:

Implementation of training programs to improve community response capacity.

Evaluation Process

Objective: Use participatory MCA to evaluate and prioritize preparedness measures.

Activities:

1) Participatory MCA Sessions:

Organization of a series of workshops with stakeholders to apply the MCA process.

2) Pairwise Comparison:

Application of a pairwise comparison method to determine the importance of each criterion.

3) Scoring Measures:

Evaluation of each proposed measure using expert judgment and available data.

Integration of Complementary Analyses

Objective: To complement MCA with economic analyses for a more complete evaluation.

Activities:

1) **Cost-Benefit Analysis (CBA):**

Quantification of the economic benefits of implementing specific measures.

2) **Cost-Effectiveness Analysis (CEA):**

Comparison of the interventions with similar outcomes to determine their cost-effectiveness.

Summary of outcomes

- **Stakeholder Engagement:** Full participation of key actors, including emergency services and community organizations.
- **Context-Specific Criteria:** Evaluation criteria adapted to the local contexts of each DEM.
- **List of Preparedness Measures:** A prioritized list of measures to improve preparedness for hydrometeorological events.
- **Comprehensive Evaluation:** Integration of participatory MCA with CBA and CEA for a balanced assessment.
- **Monitoring and Adaptability:** A plan for continuous monitoring and flexibility to adjust interventions as new data becomes available.



8. Conclusions

This report has outlined the methodologies and innovations developed in T3.2 Subtask 1, "Quantitative and Multi-Criteria Analyses for Multi- and Systemic Risk Policy Making," with an emphasis on real-world application within The HuT Demonstrators. The stakeholder-led approach, central to this task, was designed to support decision-making in disaster risk reduction and climate change adaptation by engaging decision-makers, citizens, and other stakeholders in a co-design and co-development process. This engagement fosters a deeper, collaborative environment for integrated decision-making, wherein both quantitative and qualitative data are incorporated to create resilient, multi-criteria analyses tailored to the unique conditions of each Demonstrator.

Our first application in Demonstrator 5, Glückstadt, highlighted both the benefits and challenges of implementing this methodology in a real-world setting. Limited availability of quantitative data and the demands of a stakeholder-led process led to the use of qualitative MCA. This process reinforces The HuT's vision of starting implementation with practical, grounded Demonstrator activities.

Moreover, we showcased how this approach could be transferred to other Demonstrators, adapting the methodology to varying multi-risk contexts. This continuous work, supported by WP1 and transferability, supported by WP5, sets the foundation for the wider scalability of this approach across different geographies and risk profiles, thus building resilience within and beyond The HuT framework.

Lessons Learned and Keys to Success

Applying this methodology in real-world settings has offered valuable lessons:

1. **Transparency in Decision-Making:** Building trust among stakeholders through transparent communication is crucial. Stakeholders need to understand not only the decisions being made but also the criteria and processes behind those decisions.
2. **Combining Assessment Methods:** Each assessment method brings unique strengths. By combining various approaches (such as MCA with cost-benefit and cost-effectiveness analyses), a more comprehensive and resilient decision-making process can be achieved, accommodating diverse data types and stakeholder needs.
3. **Value of the Participatory Process:** Involving stakeholders from the beginning establishes shared ownership of the outcomes, increases engagement, and bolsters the likelihood of successful implementation. This collaborative approach enables tailored solutions that are both effective and grounded in the realities of local contexts.

Future Outlook and Action Plan

Looking ahead, the participatory multi-criteria analysis methodology developed here will be adapted and expanded to other Demonstrator arenas, incorporating a broader array of multi-hazards in varying local contexts. Action plans have been set to implement this approach systematically, ensuring scalability and flexibility to address diverse risk environments.

WP1 will continue to guide and support ongoing Demonstrator activities, refining the participatory process and ensuring that the KPIs and expected outcomes are met. WP5 will further explore the transferability and scalability of this methodology, assessing how it may be applied within other frameworks, both within and outside The HuT, to contribute to broader resilience efforts. Quality assurance will remain a priority, with ongoing presentations and workshops planned for international conferences and specialized sessions with experts.



In summary, the core of this methodology lies in its participatory, flexible, and robust approach to multi-criteria decision-making for systemic risk management. Through continued collaboration, transparency, and adaptation, The HuT's approach to disaster risk reduction and climate change adaptation stands ready to support informed and resilient decision-making well into the future.



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10. Annex

Annex 1. Performance of the criteria

Measure	Criteria	Completely disagree (1)	Disagree (2)	Agree (3)	Completely agree (4)	I don't know (0)	Total Score
Improving the dike	Effectiveness	0	1	6	9	1	56
	Economic	0	1	6	9	1	56
	Equitability	0	0	2	9	6	42
	Affordability	0	0	7	10	0	61
Drainage system	Effectiveness	1	2	4	7	3	45
	Economic	0	3	4	6	4	42
	Equitability	1	1	7	4	4	40
	Affordability	2	1	6	5	3	42
Mobile pump	Effectiveness	1	6	6	2	2	39
	Economic	1	3	6	3	4	37
	Equitability	1	2	6	3	5	35
	Affordability	2	2	7	5	1	47
Sand sack	Effectiveness	0	4	8	5	0	52
	Economic	0	1	5	9	2	53
	Equitability	0	0	5	6	6	39
	Affordability	0	1	4	11	1	58
Pump at household	Effectiveness	4	4	2	7	0	46
	Economic	2	4	5	5	1	45
	Equitability	4	5	0	4	4	30
	Affordability	1	2	6	6	2	47
Rainwater catchment system	Effectiveness	0	1	7	9	0	59
	Economic	0	1	6	8	2	52
	Equitability	0	1	3	5	8	31

	Affordability	0	3	7	2	5	35
Planting tree	Effectiveness	1	1	4	8	3	47
	Economic	0	1	8	8	0	58
	Equitability	0	2	3	6	6	37
	Affordability	0	2	5	8	2	51
Green roof	Effectiveness	0	3	11	3	0	51
	Economic	1	3	8	2	3	39
	Equitability	1	5	2	2	7	25
	Affordability	0	2	6	3	6	34
Surface unsealing	Effectiveness	0	3	4	9	1	54
	Economic	0	3	7	5	2	47
	Equitability	0	3	3	5	6	35
	Affordability	0	1	7	5	4	43
Reactivation of public water dispenser	Effectiveness	2	4	7	2	2	39
	Economic	1	6	4	2	4	33
	Equitability	1	4	2	4	6	31
	Affordability	0	3	6	6	2	48
Shaded place	Effectiveness	1	2	1	3	0	20
	Economic	1	0	3	2	1	18
	Equitability	1	2	1	2	1	16
	Affordability	0	3	6	6	2	48