Delft University of Technology

# Flood Resilience through Soft Adaptation Measures. Catalog and General Evaluation

Samuel Isaac Colijn Llinares

Supervised by: Dr. Marian Bosch-Rekveldt
Dr. Maria Nogal Macho
Dr. Maria Pregnolato

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# Preface

This thesis represents the capstone of my academic journey at the TU Delft. Over my lengthy journey here, I have had the chance to delve into a plethora of interesting topics, ranging from geology and structural mechanics all the way to supply chain and legal theory. Mimicking my bachelor's thesis, I decided to once again step out of my comfort zone and tackle a topic with which I had little familiarity. The general topic was, however, not extremely foreign. Flooding is, after all, a commonly discussed subject in civil engineering. The challenging part of this project was the focus on the soft adaptation aspect, which carries a qualitative nature, due to the mix between engineering and social sciences.

Being born in the Valencian Community, in Spain, I grew up surrounded by massive infrastructure works designed to protect against sudden rainfall-induced flooding, typical in our region. I had always placed blind faith in these massive structures and believed that no matter the rain, we would always be prepared. But sadly, I was wrong. The Valencian Community was hit by a devastating flood event in late 2024. In what has now become one of the worst climate disasters in Spanish history, hundreds of people lost their lives, and there was billions worth of damage. Our flood-protection infrastructure was not enough, and when the infrastructure was unable to tackle the problem on its own, the backup systems were unable to step up to the plate.

I was surprised to find out that these "back-up systems" were actually categorized as their own part of adaptation, in the form of the soft paradigm, something I had never heard of before. This categorization was, however, subject to very little consensus. What was originally just meant to be a cataloging and evaluation project became a definition, cataloging, and evaluation project. Regardless, it was clear since day one that this topic showed significant potential. This project represents my grain of sand in better understanding what soft adaptation is, what it does, and how it can be used to maximize our flooding resilience.

The size and length of this project were a first in my life, and while the end-product is one I am proud of, I am also not afraid to admit that I struggled extensively with inspiration and motivation at certain stages. This project would never have materialized without the support of multiple people, whom I would like to publicly acknowledge. I would like to first thank my supervising team for their guidance, interesting insights, and feedback throughout the entire project. I would also like to explicitly thank Dr. Erica Arango Patiño for being the steadfast pillar who was always ready to assist me when things did not look so bright. Thank you to Michel and Marie for giving me a second home, away from my own, supporting me during both my search for a topic, the development of this one, and acting as my test subjects on which to practice my interviewing skills. Thank you, Val, for always being there for me whenever I needed it. And last but not least, thank you to my dad, to my mom, and to my brother, for everything you have done for me, during the thesis, and on the journey we took to get here.

A cualquier otra persona que tenga la oportunidad de leer este documento, muchas gracias por invertir tu tiempo en leer mi trabajo. Espero sinceramente que disfrutes de mi proyecto y que encuentres algo digno de tu interés en estas páginas.

*Samuel Isaac Colijn Llinares 4695917*
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# Executive summary

**Introduction**
Flooding represents one of the most relevant threats brought upon by the impacts of climate change. Expectations indicate that both the number and intensity of these events will increase significantly in the near future. The European Union, in particular, stands to be severely impacted by flooding due to the elevated urbanization within, which can exacerbate local flooding. The location of many urban centers along areas with increased vulnerability to flooding, such as floodplains and river deltas, is another aspect to consider. This, combined with the understanding that some consequences are irreversible, has led to a significant investment in climate change adaptation.

Adaptation to climate change refers to the introduction of modifications aimed at reducing the risk of crisis events. Adaptation happens by reducing the vulnerability or exposure prior to the event, or by reducing the consequences after it. Adaptation can be further subdivided into two main paradigms: the "hard" one, centered on infrastructure-based measures, and the "soft" one, focused on social, educational, institutional, and economic policies. Both approaches aim to increase the resilience of the underlying society.

Over the last couple of decades, academic literature has studied the assertion that a combination of measures aligned to each paradigm is the optimal approach to maximize resilience. While studies have analyzed and found the assertion to be correct, there are still, to this day, challenges to address. The root of most of these challenges arises from the paradigms of "hard" and "soft" adaptation themselves, which remain vaguely defined and, by extension, inconsistently applied. Additional difficulty arises from the challenge of quantifying "soft" adaptation measures themselves. Subsequent literature has argued that "soft" adaptation struggles with quantification due to the increased focus on economic aspects shown by currently used decision-making systems.

Some studies have evaluated adaptation measures, including those adhering to the "soft" paradigm, and found them to be cheaper, subject to less regret and lock-in, and capable of increased reversibility & flexibility.

**Research questions & structure**
The research project is subdivided into three main sections, denoted internally as research blocks. They are:

1. *What constitutes a soft adaptation measure?* (Research block 1)
2. *What types of soft adaptation measures are commonly used for flooding* (Research block 2)
3. *What are the advantages and disadvantages of each of the soft measures?* & *What is the interaction with other adaptation measures?* (Research block 3)

Each of the blocks acts as a self-contained unit and they build up subsequently upon each-other. The final objective of the research is to answer the following question:

*How can soft adaptation measures influence flooding resilience in an urbanized environment?*

**Research block 1**
The first section of the project provides a formalized set of definitions for "soft" and "hard" adaptation measures. This definition is crafted following previous definitions, both from within and outside the field. The practical usage seen currently in the field of adaptation is also incorporated. The "soft" paradigm is defined as:

*Including measures that rely on social, institutional, educational or economic systems.*

**Research block 2**
The second section of the project utilizes the new definition of "soft" adaptation to consistently catalog the adaptation measures aligning to the paradigm that see common usage in the field. The field focus is flooding in the urban sphere. Additionally, this research provides a new categorization system for measures, aligned with current practices. The full catalog is shown in table [5.3.2], but a shortened version of the resulting categories and sub-categories of soft adaptation is included here:

| Category | Sub-category | Example of soft measure |
|---|---|---|
| Social | Evacuation | Escape route planning |
| | Warning systems | Early warning system |
| | Educational | Information campaign |
| Institutional | Regeneration | Insurance protocol |
| | Zone management | Urban zoning restriction |
| | Administrative | Emergency protocols |
| General | Evaluation | Simulations |

**Table 1:** Categories and sub-categories for soft adaptation measures.

**Research block 3**
The third section addresses the quantification of the soft adaptation measures. This data gathering for this quantification happened through semi-structured interviews with eight experts: seven from the Netherlands; one from Spain. The experts were drawn from multiple layers of society, and whose work has an impact on flooding resilience in the urban space. Both of these criteria were developed from relevant literature.

The interviews themselves involve structured sections, where the experts were asked to rank the seven groups of soft adaptation measures (plus a group representing hard adaptation) on multiple criteria, visible on table [6.1]. These structured sections were followed by unstructured sections where experts gave personal insights or justifications for the ranks. The interviews yielded two results:

1. Sets of ordinal data, where experts ranked measures comparatively based on the agreed criteria. There were 8 sets of rankings (one per interview) for each of the 5 criteria (interaction was analyzed on its own).
2. General insight logs, gathered from the interview discussions and summarizing important discussion points or relevant peculiarities revolving around the ordinal rankings they provided.

The sets of ordinal data acted as the base for the qualitative analysis, which was performed in the shape of an MCDA. For the preliminary work, the rankings were normalized into the median and inter-quartile range. This is to see what the average ranking of each measure was and how representative that average was of the entire picture. The qualitative analysis then utilized the insight logs to evaluate the rankings, discuss peculiarities and justify the results, effectively also acting as a validating stage. The statistical results are not utilized further due to their function as preliminary work. They are replaced by a comparison between each of the soft adaptation measure groups, and the hard adaptation group, which acts as an anchor. The end results for the analysis are shown in table [7.1]. A simplified version follows:

- Soft adaptation measures show, in general, lower average implementation costs. They also show higher flexibility & reversibility once deployed when compared to hard adaptation measures.
- Soft adaptation measures show, in general, significantly higher required end-user engagement.
- Soft adaptation measures are more mixed when evaluating the ability to garner political support. They are also difficult to evaluate in detail on their cost-efficiency.

The topic of interaction is directly analyzed through qualitative means, with no usage of the ordinal rankings. The preparatory work therefore involves the creation of a network of measures, where-in the potential pathways of interaction are charted, this is visible in figure [7.1]. From this chart, it is possible to review the insight logs to discern the interaction between measures entails. The research finds the following three types of positive interaction:

1. Interaction between measures, aligning them to become a cohesive unit that is better than the sum of its individual parts parts.
2. Interaction through the end-user, which becomes more self-sufficient and more receptive to engagement from other measures.
3. Interaction through information, improving the decision-making by increasing the pool of information and aligning long-term objectives of policymakers.

**Conclusion**
Soft adaptation measures can increase the resilience of the urban environment to flooding in three main ways.

1. Due to their capability to transform flooding adaptation into a multi-layer strategy.
2. Due to their strong interaction with other adaptation measures, which helps align strengths and minimize vulnerabilities, and increases the resilience of the system overall
3. Due to their increased involvement of the end-user, which becomes more responsive and self-sustaining, effectively making the populace itself more resilient to flooding.

Additionally, the results of the project strengthen the assertion that introducing soft adaptation measures next to hard adaptation into the flooding strategy is optimal, due to the multi-layer approach and measure alignment.

**Study limitations**
The study presents limitations mainly on its non-exhaustive nature. The limited sample size of experts is also of relevance. Additionally, due to the vast majority of them hailing from the Netherlands, it may make extrapolating the results to other parts of the world difficult, where societal and cultural aspects or the approach to flooding resilience differ significantly.

**Recommendations**
Further research into the topic is strongly recommended, mainly in the following topics:

1. The paradigms of hard and soft adaptation must be expanded and updated to remain useful in an ever-evolving field.
2. The topics of end-user engagement and derived "social capital" are also of high interest. An in-depth study would involve social sciences and plenty of interviews with stakeholders and measure end-users.
3. The concept of interaction also remains quite relevant for future research. This project briefly discusses three types of positive interaction, but does not develop or explain how exactly they might function. The potential for negative interaction is acknowledged, but not developed.

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# 1

# General introduction

Climate change has become one of society's central challenges. Public perceptions surrounding climate change have shifted considerably in recent times, and reports published by major policy developers have followed this trend. In its annually published "Global Risks Report," the World Economic Forum identifies environmental challenges as four of the top five risks to global economic activity over the next decade. Extreme weather events rank the highest, topping the list (Forum 2024). Extreme weather events are generally considered to include, among others, aggressive temperature events in the form of heatwaves; disruptive precipitation patterns with significant increases or decreases in total accumulation, and flooding events (Forum 2024).

Climate change presents a significant threat to the European Union and the continent as a whole. Flooding events, in particular, present a significant challenge to European policymakers, due to the large number of urban centers and their tendency to be located within areas characterized as floodplains. In their December 2020 report, the European Environmental Agency remarks on the increased vulnerability displayed by European cities to flooding events, including precipitation, river flow, and coastal-based flooding (Kazmierczak et al. 2020). This report seems to evoke the general increasing focus on flooding events, exacerbated by recent mass casualty events, such as south-eastern Spain in October 2024 (BBC 2024; Tanno et al. 2024), and central Europe during July 2021 (News 2021; CNN 2021).

Climate change policy is centered on two strategies:

1. Mitigation seeks to reduce the root of the problem, that being carbon emissions, and policies following this approach seek solutions at the base.
2. Adaptation focuses on altering human systems and dealing with the consequences of those changes that cannot be fixed anymore (WWF 2022; Campbell and Krol 2023).

While both of these strategies work towards the same goal, the way they approach the problem is fundamentally distinct, and as such, they have all been seen as competitors for a long time. Since resources are limited and the time pressure is constantly increasing, climate change remains to this day a significant challenge for policymakers to properly address (Dolšak and Prakash 2018).

## 1.1. Problem statement

The limited resource pool has resulted in policymakers prioritizing mitigation to minimize climate change altogether. Results have been mixed (Campbell and Krol 2023; Nations 2023), and it has become clear that climate change will be permanent and its consequences significant (IPCC 2023). Adaptation has therefore become important and garnered increased attention from policymakers, but not at a sufficient rate (Nations 2022).

Limitations on adaptation knowledge appear to be the main problem behind the slow shift of focus (Nations 2022). One of these limitations concerns the internal subdivision between hard and soft adaptation approaches (Dolšak and Prakash 2018). Adaptation measures are considered to adhere to the hard approach when they rely on artificial centralized infrastructure; measures adhering to the soft approach, on the other hand, are comprised of natural infrastructure or policy and have a more localized impact (Sovacool 2011).

Several studies have researched the division between the soft and hard adaptation strategies to ascertain which combination of adaptation measures presents the best success rate. The consensus has been that a combination of measures adhering to both the hard and soft strategy is optimal (Dolšak and Prakash 2018; Sovacool 2011). Two main limitations impact the veracity of this assertion:

1. The original definitions of soft and hard adaptation are general. Therefore, significant personal interpretation happens in every subsequent usage of the definition. Recent research includes measures in the soft adaptation strategy in an inconsistent manner.
2. Adaptation measures, particularly those adhering to the soft strategy, are difficult to compare to an optimal benchmark. Their apparent incompatibility with current evaluation methods, which focus excessively on economic aspects, appears to be the root of the problem.

The apparent lack of consensus, together with the limited overall information regarding soft measures, provides the basis for this project. It will be beneficial to consolidate the definitions of the soft and hard adaptation strategies, creating a stable base. It will be beneficial to provide an itemized list of the types of soft measures generally used, in this specific case, on flooding adaptation, with an overview of their costs and benefits. Lastly, it will help strengthen the argument that soft and hard adaptation work best when combined if the interaction of soft adaptation measures with other measures is better understood.

## 1.2. Reading guide

This thesis is split into several chapters. Chapter [1] includes the general introduction to the project, along with the problem statement. Chapter [2] covers the literature review, including the concepts of adaptation and mitigation, the soft and hard paradigms, some reviews of previous adaptation catalogs, and an overview of water management in the Netherlands. Chapter [3] concerns the research framework for the thesis, also including the research gaps, research questions. Chapter [4] focuses on the creation of a new definition for soft and hard adaptation measures. Chapter [5] centers on the gathering and categorization of soft adaptation measures into a measure catalog, with a focus on flooding in the urban sphere. Chapter [6] concerns the gathering of data through semi-structured interviews in order to analyze the capabilities of the soft adaptation measures cataloged previously. Chapter [7] covers the interpretation of the data gathered previously, in order to better understand soft adaptation measures. Chapter [8] provides a discussion on the results of the previous four chapters and illustrates the limitations faced by the research. Chapter [9] closes the thesis, and includes the final answers to the research questions and some recommendations for future research.

# 2

# Literature review

This section covers the literature review for the project. It is internally subdivided into four sections. Section [2.1] opens the literature review and covers the topics of mitigation and adaptation within the climate change field. Section [2.2] covers the paradigms of soft and hard, from their original meaning to the one developed within the adaptation field. Section [2.3] covers the decision to exclude nature-based solutions from soft adaptation and include them in hard adaptation. After this subject, section [2.4] goes over some analyses and catalogs performed on adaptation measures in the past. The chapter is closed by section [2.5], which discusses the governance structure for flooding protection and water management in the Netherlands.

## 2.1. Mitigation and adaptation

The first step to understanding any climate change resilience involves understanding the two pillars encompassing the policies targeting it. Those are mitigation and adaptation (WWF 2022; Campbell and Krol 2023); their approaches are not competitive, but complementary in nature, with each attacking the problem from different sides (Behsudi 2021). This section discusses them individually, with some discussion on internal subdivisions and current challenges they face. An overview is provided at the end.

### 2.1.1. Mitigation

According to the IPCC, mitigation is defined as "The human intervention to reduce emissions or enhance the sinks of greenhouse gases" (IPCC 2022). Building from this, mitigation measures are then defined as processes, technology, or protocols that enhance mitigation (IPCC 2022). Mitigation is further split into two groups of action.

1. Emission reducing: Since almost 75% of greenhouse gases come from burning fossil fuels (Campbell and Krol 2023), mitigation measures in this group tend to encourage transitioning away from fossil fuels into renewable energies with lower lifetime-adjusted emissions (Campbell and Krol 2023). Some specific examples of mitigation measures in this group include carbon pricing, essentially an extra tax paid based on emissions made (Behsudi 2021), or heavily restricting the usage of coal-based energy (Campbell and Krol 2023).
2. Enhancing sinks: These measures focus on eliminating greenhouse gases already present in the atmosphere (Campbell and Krol 2023). Mitigation measures adhering to this group work to enhance or create new pollution sinks (Campbell and Krol 2023). Specific measures include the creation of new green surfaces (forests) or the development of carbon-capturing technologies and systems.

Mitigation policies, therefore, attempt to curtail emissions and extract greenhouse gases from the atmosphere to reverse climate change, but currently, mitigation has been a significant failure. This failure is exemplified by the Paris Accords (IPCC 2023), a worldwide set of treaties intended to ideally limit global temperature rise to 1.5 °C and a hard maximum of 2 °C (Campbell and Krol 2023). Current

estimations of temperature rise sit at 2.5 to 3 °C, and emissions continue rising every year (Nations 2023). The carbon tax, currently sitting at an average of $3 US per ton, also falls well short of the theoretical $75 US per ton needed to curtail emissions (Behsudi 2021).

The reasons behind the failures of mitigation are generally attributed to the political game (Dolšak and Prakash 2018). Mitigation measures provide generalized and non-excludable benefits to everyone, but their cost remains heavily localized, raising a significant challenge from a policy management perspective. Policy-makers, therefore, have been incentivized to cheat on their voluntary commitments (Victor and Ebrary 2001; Dolsak 2005).

The widespread failure of mitigation measures, added to the reality of the majority of consequences arising from climate change being permanent, has led to the increased focus away from mitigation measures into adaptation (IPCC 2023).

### 2.1.2. Adaptation

According to the IPCC (2022), adaptation carries a slightly different definition when covering human or natural systems. In human systems, which are the most relevant for this study, adaptation refers to the process of adjustment to actual or expected climate change and its consequences, to moderate harm or exploit beneficial opportunities (IPCC 2022).

Adaptation is highly variable. Its approach can differ based on what each place requires (Behsudi 2021; Campbell and Krol 2023). Adaptation differs from mitigation in that measures are not grouped by what they do. Measure categories are instead based on how they do it. This grouping approach, added to the variability displayed by adaptation measures, creates the potential for significant category overlap Noble et al. 2014. The specific categories are the following (IPCC 2022; Campbell and Krol 2023):

1. Structural: Adaptation measures in this group focus on the utilization of artificial infrastructure to combat the consequences brought upon by climate change. Some examples include dikes, river channel relocation, storm surge barriers, etc.
2. Institutional: Measures in this group encompass adaptation undertaken in the governance infrastructure of human societies to combat climate change. Examples include regulation and legislation changes, emergency protocols of action, etc.
3. Ecological: This adaptation encompasses measures that utilize natural functions to fight climate change consequences. Wetlands and floodplain restoration or controlled flora changes are examples of ecological adaptation.
4. Behavioral: Measures that target individual end-users and attempt to change their perceptions or approach towards climate change and its consequences. Examples would encompass education campaigns, emergency evacuation plans, or general warning systems.

Adaptation policies carry local benefits and localized costs, which would theoretically make it very attractive to policymakers (Dolšak and Prakash 2018). Economically speaking, adaptation is also smart, since it is calculated that every $1 US spent on it is returned tenfold in avoided damages (Behsudi 2021). This theory has, however, not materialized, and even though money is flowing into adaptation (IPCC 2023), it is not doing so at a pace capable of keeping up with the expected demand (Nations 2022). The current failure to adapt quickly and consistently hinges on several problems:

1. Capital costs are elevated, and due to the ex-ante nature of adaptation, upfront, which creates significant challenges from an economic perspective since perceived benefits do not materialize in actual income, but in avoided losses(Behsudi 2021). This challenge is exacerbated in countries with low financial development, which usually have low emissions but find themselves extremely vulnerable to climate change and lack the funds to properly protect themselves, potentially starting a vicious cycle (Campbell and Krol 2023; Behsudi 2021).
2. It struggles politically due to the current implementation approach, clashing with sub-optimal policy frameworks that impact actor behavior (Ostrom 2015; Dolsak 2005) and their subjective beliefs over climate change adaptation requirements (Adger, Barnett, et al. 2012; Adger, Dessai, et al. 2009). These decision-making frameworks would be expensive (economically, socially, and

politically) to replace, and as such, it is unrealistic to do so (Dolšak and Prakash 2018). At the same time, the current implementation strategy, which adheres to mathematically optimal solutions, is not a realistic prospect in the current environment (Bergh 2004).

3. Not all adaptation measures can be easily quantified, and even if they can, the current approach based on cost-benefit analyses probably does more damage than good (Bergh 2004). As previously mentioned, actors have different views on the vulnerabilities to climate change (Adger, Dessai, et al. 2009; Adger, Barnett, et al. 2012). Additionally, adaptation measures come in two dimensions, hard and soft (Sovacool 2011), and soft measures are not able to be bench-marked to a theoretical best, which makes finding mathematical optimums impossible (Dolšak and Prakash 2018). This is arguably a central cause for most of the issues with adaptation implementation.

### 2.1.3. Adaptation and mitigation overview

Mitigation and adaptation are the two pillars among which climate change policy stands (Campbell and Krol 2023; Behsudi 2021; Dolšak and Prakash 2018). In figure [2.1] it can be seen that mitigation focuses on policies meant to reduce emissions or capture emissions already present, effectively acting "prior" to climate change (Campbell and Krol 2023; Behsudi 2021). Adaptation, on the other hand, focuses on protecting against the consequences brought upon by climate change that has already happened, conceptually working "after" it (Campbell and Krol 2023; Behsudi 2021). Ideally, investment would target both adaptation and mitigation (Howarth 2024), but so far, mitigation has prevailed in the policymaking sphere (Campbell and Krol 2023). The current failure of mitigation policies has drawn increased interest in adaptation (Nations 2023), but so far this interest has not materialized fast enough due to problems within adaptation implementation strategy (Nations 2022; Dolšak and Prakash 2018; Bergh 2004), out of which the inability to quantify adaptation measures described as soft stands out (Dolšak and Prakash 2018).

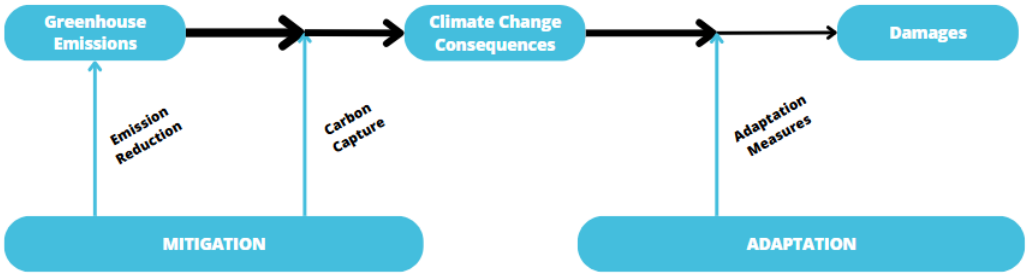



**Figure 2.1:** Conceptual Framework showing the timeline of Mitigation and Adaptation measures.

## 2.2. Soft and hard measures

The lack of adaptation implementation lies mainly with adaptation measures aligned to the soft strategy (Dolšak and Prakash 2018). The inability of scientists and policymakers to benchmark soft adaptation measures against a theoretical optimum has led to adaptation implementation showing a significant bias towards measures aligned to the hard strategy, since they can be quantified in a manner compatible with the current policy-making framework (Dolšak and Prakash 2018; Bergh 2004). An important discussion arises around the fuzzy nature of the soft and hard adaptation groupings, with recommendations that scholars revisit the definition (Dolšak and Prakash 2018) prior to attempting to solve the quantifying issue.

### 2.2.1. Origin of the classification

The first known usage of the concepts of hard and soft policies arose during the Petroleum Crisis of 1970, from American Physicist Amory D. Lovins, who used it to describe the two energy strategy paths presented to Western countries (Amory B. Lovins 1976; A B. Lovins 1978b; A B Lovins 1978a). According to Lovins, they encompassed the following:

1. The hard path is centered on utilizing non-renewable resources, with a poor match in scale and quality to the end-usage. This path is also complex and cannot be easily understood by a single

person. Additionally, it is highly inflexible to changes in demand and lacks resilience due to centralization in large energy production facilities.

2. The soft path instead focuses on decentralized energy production facilities. The decentralization increases resilience due to risk diversification. It is also simpler and matches in scale to the energy end-use. This simplicity allows for modularity, which provides it with flexibility to sudden changes in demand.

Additionally, Lovins argues that the true challenge between the soft and the hard path lies in the way policymakers approach the problem and that the paths are socially incompatible since they represent inherently different mindsets with regard to energy production (Amory B. Lovins 1976; A B. Lovins 1978b; A B Lovins 1978a).

### 2.2.2. Soft and hard adaptation

The paradigms of soft and hard adaptation did not become prevalent in the climate change field until the late 2000s and early 2010s, when two papers discussed the concepts while covering climate change Adaptation strategy. Both papers are discussed individually.

The 2009 paper by Hallegate covers soft measures without giving a quantitative definition. Within the paper, it defines soft measures as those that do not adhere to technical solutions, and instead target economic or financial solutions to climate change (Hallegatte 2009). Specific examples mentioned include insurance schemes, early warning systems, and land-use plans. It is argued that soft adaptation measures are also highly reversible since they can be quickly revisited and modified without incurring significant costs (Hallegatte 2009). Their flexibility is further noticed when considering that soft measures involve significantly smaller sunk costs when compared to their hard counterparts, which makes them suitable in the current uncertainty sphere (Hallegatte 2009). Additionally, Hallegate (2009) observes that properly implemented soft-adaptation measures often impact decisions relating to hard measures. Due to their nature impacting infrastructure decisions, he argues that there are almost no purely soft adaptation measures (Hallegatte 2009).

The 2011 paper by Sovacool provides much more concrete definitions for what soft and hard adaptation measures would entail. The definitions as derived from a *mutatis mutandis* approach to the works of Lovins (Amory B. Lovins 1976; A B. Lovins 1978b; A B Lovins 1978a).

1. According to Sovacool (2011), the Hard Adaptation Path would:

   - Rely primarily on artificial human-built infrastructure,
   - Involve large-scale disturbances to local communities and/or ecosystems,
   - Be complex and capital-intensive,
   - Use technologies and/or processes owned by foreign firms,
   - Lack flexibility and reliability to sudden changes in climate change predictions.

   The hard path would therefore bring communities and environments in line with human needs, through a large investment of capital with high rigidity (Sovacool 2011). The concept of development lock-in is also brought up due to the longevity of measures adhering to the hard adaptation path (Cole, Brown, and McKay 2010; Hassler 2009).
2. On the other hand, Sovacool (2011) argues that the soft adaptation path would instead:

   - Involve forms of natural infrastructure or natural capital, together with low-impact technology,
   - Empower local communities and build institutional capacity and community assets,
   - Use simple and modular technologies, relatively easy to understand, that do not require large outlays of resources,
   - Involve technologies or processes owned by local people,
   - Have the ability to respond to alterations in climate change projections.

   The soft path would incur less investment, remain relatively flexible to unpredictable changes, and involve small-scale decentralized adaptation measures (Sovacool 2011). It would bring adaptation needs in line with community and environmental needs (Sovacool 2011). Soft path measures are considered similar to community-based adaptation schemes owing to their similar scale, reliance on local stakeholders, and location-specific variance (Ayers and Forsyth 2009).

In the closing pages of the 2011 paper from Sovacool, some conclusions are shared. Hard and soft adaptation paths require different approaches to the same problem, sparked by their intention to bend nature's needs to the adaptation efforts or bend adaptation efforts to the natural needs (Sovacool 2011).

From this perceived institutional incompatibility arises the possibility that they may not be applicable at the same time due to the limited resources present in real life. It is therefore argued that embracing both paths simultaneously remains ineffective (Sovacool 2011). The difficulty in fully embracing both paths at the same time doesn't preclude them from being complementary based on local needs, so it is not optimal to fully disregard one side against the other. As such, optimal adaptation policy involves a combination of both soft and hard adaptation measures (Ostrom 2009; Ostrom 2010).

Lastly, there is a clear and significant bias away from soft adaptation measures due to their appeasement of different interests (Sovacool 2011). Ayers and Forsyth (2009) even propose a reason behind the inherent bias, arguing that Western actors target hard adaptation measures since they have been proven to work.

In the 2018 paper published by Dolšak and Prakash, a new contextual definition of Soft Adaptation Infrastructure is provided. Central Key-points include:

1. In order to better secure hard adaptation Infrastructure, it is necessary to invest substantially in the technical, organizational, and social capacities of administrative and social systems required to respond to climate change (Sovacool 2011; Ebert, Hulea, and Strobel 2009). This is soft adaptation Infrastructure (Dolšak and Prakash 2018).
2. Soft adaptation also has a significant component of citizen-government interaction, since many of its aspects are co-produced (Bovaird 2007; Parks et al. 1981). Due to the individual nature of a significant number of policies within soft adaptation, it is argued that governments alone cannot properly engage measures effectively, and individual actors must be engaged to undertake them of their own volition (Dolšak and Prakash 2018). A strong analogy to the public health field is drawn, where a significant number of policies invest effort in the end-user; engagement and social capital are particularly salient (Szreter and Woolcock 2004). Public health policies generally work in a preventive manner, aiming to reduce vulnerability and increase resilience to sanitary threats (Ebi and Semenza 2008). A clear analogy is drawn with soft adaptation measures (Dolšak and Prakash 2018).
3. There is an apparent bias against soft adaptation measures. They argue that soft adaptation measures are not easily implemented due to their inability to be benchmarked adequately against a mathematically theoretical optimum (Dolšak and Prakash 2018). Even then, there is extensive debate on whether the current analysis methodology even provides an appropriate description of adaptation policy benefits (Brooks, Neil Adger, and Mick Kelly 2005; Eriksen and Kelly 2006; Preston, Westaway, and Yuen 2010).

Lastly, the 2018 paper discusses the significant benefit soft adaptation stands to gain if its definition is further refined, as it currently remains too vague and exacerbates some of the problems within (Dolšak and Prakash 2018).

### 2.2.3. Hard and soft adaptation measures overview

The terms were created to differentiate two potential policy directions to take regarding energy (Amory B. Lovins 1976; A B. Lovins 1978b; A B Lovins 1978a). Their original meanings described the hard path around inflexible, capital-intensive, and non-renewable resource-dependent infrastructure, while the soft one encompassed flexible, simplified, renewable-based infrastructure projects. These definitions displayed an elevated bias against the hard path.

These paradigms slowly permeated the climate change field and were provided an official definition through the works of Sovacool (2011). In the adaptation lens, the hard path refers to artificial infrastructure-based adaptation, while the soft path encompasses everything else. Scholars have transitioned away from the preference for infrastructure, and an apparent consensus on the importance of both paths has been reached (Ebert, Hulea, and Strobel 2009; Ostrom 2009; Ostrom 2010). More modern

works have challenged the definition provided by Sovacool (2011), due to it being too generalized, and have further specialized it only to encompass social or institutional adaptation (Dolšak and Prakash 2018). Additionally, there have been longstanding problems quantifying (Bergh 2004) and properly implementing these social and institutional policies (Bovaird 2007; Parks et al. 1981). These problems predate the definition of soft adaptation itself.

Figure [2.2] provides a visual overview of the evolution of the definitions for soft and hard, from the energy field to the adaptation field.

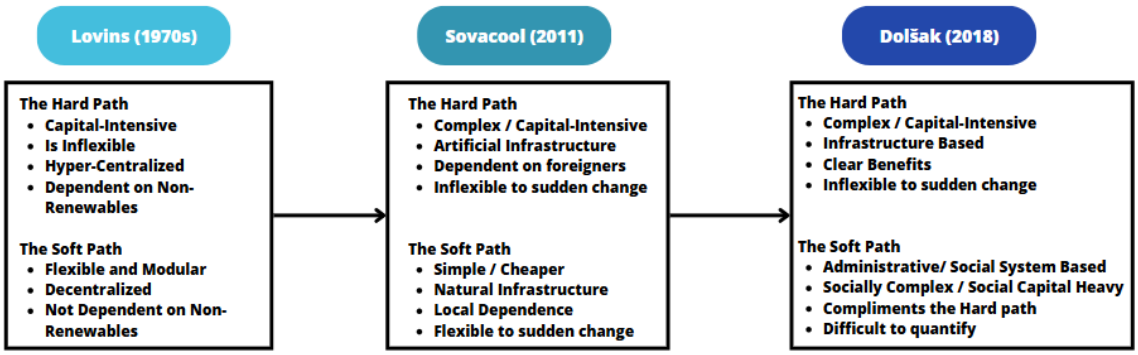



**Figure 2.2:** Definitions of Hard and Soft Paradigms over time.

## 2.3. Nature-based solutions

The topic of nature-based solutions warrants some additional discussion when covering hard and soft adaptation measures. Nature-based solutions are defined as the utilization of nature and/or natural processes to address socio-environmental issues (Frantzeskaki et al. 2019;Girardin et al. 2021). The objective is to create or nurture resilient ecosystems, and these provide solutions to current environmental threats (Eggermont et al. 2015).

When looking at the historical definition progression of the soft path paradigm, shown in figure 2.2, a noticeable trend is present in the form of the ever-changing classification of adaptation measures adhering to the nature-based solutions group. Originally, Lovins associated the soft path with renewable sources of energy and decentralized projects (Amory B. Lovins 1976; A B Lovins 1978a; A B. Lovins 1978b). Sovacool (2011) provided a *mutatis mutandis* definition and associated the soft path with smaller-scale nature-based infrastructure projects, mirroring the environmentally friendly approach Lovins seemed to link with the soft path (Sovacool 2011).

This grouping has become problematic in more recent reviews due to the ever-present bias towards infrastructure projects (Dolšak and Prakash 2018), both due to their proven track record (Ayers and Forsyth 2009) and their easier quantifiable nature with current policymaking approaches (Brooks, Neil Adger, and Mick Kelly 2005; Eriksen and Kelly 2006; Preston, Westaway, and Yuen 2010). The association of nature-based solutions as soft measures in the adaptation path has further alienated social, institutional, or behavioral adaptation measures, inherently exacerbating adaptation research on heavy infrastructure reliance, irrelevant of whether that infrastructure is artificial or natural in origin. This is noticeable in modern papers consistently categorizing nature-based infrastructure projects as soft adaptation, with a significant disregard for non-infrastructure-based measures (Cai et al. 2024; Moon et al. 2024).

The social perception of nature-based infrastructure as soft adaptation has to be addressed to eliminate the problems arising from the currently fuzzy soft adaptation measure definition (Dolšak and Prakash 2018).

## 2.4. Adaptation measure catalogs & analyses

Since adaptation started to permeate into the general field of focus, there have been plenty of attempts to analyze and discern which adaptation measures perform best, intending to assist policymakers with decision-making.

In their 2009 paper, Hallegate performed a brief analysis on how adaptation measures fared when dealing with the uncertainty attached to climate change predictions (Hallegatte 2009). The analysis is quite general, including adaptation measures from a plethora of sectors, ranging from agriculture to coastal management. The criteria used for the analysis revolve around uncertainty management, more specifically:

1. No-regret strategy: If climate change does not happen, is the investment wasted?
2. Reversible | flexible: How easy is it to change the adaptation measure if needed?
3. Existence of cheap safety margins: How easy it is for measures to over-prepare?
4. Reduced decision horizon: How fast are decisions renewed?
5. Synergies with mitigation: How does the adaptation measure interact with mitigation measures?

On top of these criteria, the paper introduces a special adjective in the form of a "soft strategy" (Hallegatte 2009). This mention of the term in this paper is one of the first mentions in the climate change field and has already been covered in previous subsections. From the resulting analysis, Hallegatte ranks the adaptation measures based on their favorability in the current environment. All measures denoted as soft rank in the highest category, owing to their elevated reversibility and low regret (Hallegatte 2009).

The 2014 IPCC report, part of the fifth synthesis report on climate change, provides one of the largest adaptation measure catalogs available; it is also one of the most commonly cited. The focus is general, and it includes measures from most sectors. The categorization is split into three main groups (Noble et al. 2014):

1. Physical adaptation measures: This includes the subcategories of structural, technological, ecosystem-based, and services.
2. Social adaptation measures: It is further subdivided into educational, informational, and behavioural.
3. Institutional adaptation measures: It includes the subcategories of economic, laws and regulations, and government policies & programs.

The categorization is explained as not being authoritative, and that future research is likely to utilize different categorizations (Noble et al. 2014). The categories are argued to be subject to significant overlap and ambiguity. Additionally, the report includes a section discussing the parameters relevant when analyzing multiple options. Among the considered criteria to analyze are the following:

1. Stakeholder participation, engagement, and support.
2. Efficiency, reducing costs and providing benefits.
3. Legitimacy and social acceptability.
4. Flexible and able to respond to feedback.
5. Matching the resources available.
6. Coherence and synergy with other measures.

The report does not perform any analysis on measures themselves, but acts as a foundational guide aimed at assisting future research.

The 2020 paper from Baills et al. (2020) provides a recent adaptation measure analysis. The scope of the analysis is limited to the coastal protection of South-Western France (Baills, Garcin, and Bulteau 2020). Some considerations are made to facilitate extrapolation to the general field, the most important of which is the exclusion of any social or economic aspects. This exclusion is a high price, as these two aspects are considered of high relevance (Boruff, Emrich, and Cutter 2005) and recommended to be

researched in each specific context (Baills, Garcin, and Bulteau 2020).

Overall, Baills et al. (2020) provide a new categorization scheme for the adaptation measures, comprising four categories. They are the following:

1. Measures addressing hazards: The category is split into hazard mitigation, hazard counteraction, soft engineering, and hard engineering.
2. Measures addressing assets: The category aligns with the coastal management approach of reducing vulnerability. It includes flooding reduction, erosion reduction, and general vulnerability reduction.
3. Measures for flexible management: It is split into two subcategories: natural evolution under monitoring, and accompaniment of natural processes.
4. Complementary measures: They do not specifically target any particular management method, but they provide an optimal environment for other measures. They include educational, knowledge, information, or urban planning.

The analysis is performed on 10 different criteria, including: life expectancy, robustness, synergy with mitigation strategies, no regrets, implementation costs, etc.

The final results of the MCDA from Baills et al (2020) show strong performances from complementary measures, which form the overwhelming majority (11 out of 17) of the measures that score highly in robustness, no regret, and flexibility, simultaneously. This strong performance continues when introducing a short decision horizon and immediate benefits to the required high scoring criteria, albeit less so (7 out of 13).

An important consideration in the paper concerns the fact that complementary measures are, by definition, not meant to be utilized on their own (Baills, Garcin, and Bulteau 2020). They are instead meant to act as a supplement to another measure.

Lastly, it is argued that any analysis that aims to be of utility in decision-making must account for the socio-economic peculiarities of the target area of interest and further tailor the criteria used to the local requirements (Baills, Garcin, and Bulteau 2020).

## 2.5. Flooding and water management in the Netherlands

Flood protection represents an integral part of government policy in the Netherlands, owing to 25% of the land lying beneath sea level. This reality, together with the elevated urbanization in the country, places a majority of the population under significant threat of flooding risks if mismanaged. In the Netherlands, water management is primarily the responsibility of Rijkswaterstaat and the water boards (Algemene Zaken 2017).

1. Rijkswaterstaat is a subdivision of the national ministry of water management and infrastructure, and focuses primarily on national water management policy. This ranges from maintaining and constructing dykes and dams to issuing warnings to other ministries prior to water-related crisis events.
2. The water boards focus on water management within their designated region. This management includes, among others, flooding protection and wastewater management, but can vary depending on the board's size. Some of the larger ones also maintain channels and internal dykes.

Municipalities and provincial governments also have a part in water management, but in a more focused manner, usually limited to their area of jurisdiction or expanding outwards to assist smaller neighboring settlements (Algemene Zaken 2017).

Due to the ever-present focus on flooding in the Netherlands, there is a strong connection between the private and public sectors on the topic. Private consultants and water authorities have close contact and often work together (NWP 2025). The educational sector also has very close contact with the water authorities, to update and develop new strategies aimed at improving water management (NWP 2025).

# 3

# Research structure

This chapter is subdivided into three main sections. Section [3.1] addresses the research gaps drawn from the literature review. Section [3.2] concerns the research questions. Section [3.3] provides an overview of the general research framework that drives the thesis.

## 3.1. Research gaps

The literature review reveals the presence of some academic gaps within the topic of soft adaptation measures in urban environments, and three main gaps are formally defined:

1. A conceptual research gap, since it is clear that papers do not consistently agree on what even constitutes a soft adaptation measure within the climate resilience field. Papers limit themselves to quoting or referencing previous documents while maintaining a consistent level of subjectivity and not trying to define or catalog options properly. This gap can be observed in the varied definitions provided by papers:

   (a) Hallegatte (2009) provides one of the first definitions of soft adaptation and focuses it purely on institutional and financial tools.
   (b) Sovacool (2011) then defines soft adaptation as simple and using natural infrastructure, with no mention of institutional or financial tools.
   (c) Dolsak and Prakash (2018) change the definition to exclude infrastructure altogether and focuses it purely on social and administrative systems once again.
   (d) Baills et al. (2020) then define soft adaptation measures as those that do not restrict the natural flow of coastal erosion, with no mention of any social/administrative systems, which are explicitly categorized elsewhere.

   The chaotic definition expands to eligibility criteria, where some papers include some measures in a soft group (Hallegatte 2009), while others directly exclude them from the category based on different interpretations of the same original criteria (Baills, Garcin, and Bulteau 2020). This theoretical gap is also noticed in their interaction, where the interaction between measures is discussed briefly but never fully explored or charted (Dolšak and Prakash 2018).
2. A knowledge gap. No literature overview provides a discussion on all the potential options available within soft adaptation, much less with a focus on flooding. Literature limits itself to enumerations or evaluations (Noble et al. 2014; Baills, Garcin, and Bulteau 2020; Hallegatte 2009)
3. An empirical gap. There is little empirical data on soft adaptation measures from different projects. Research remains general and avoids social aspects to allow for the data to be expanded to a general picture, as the specificity of focused social research would preclude it from being used in general research (Boruff, Emrich, and Cutter 2005).

The nature of these gaps creates the following situation: General results arise from research projects on a semi-consistent basis, but this information is not easily utilized and/or understood due to a lack of clear and consistent definitions within the topic. This lack of clarity and consistency has complicated the compilation of soft adaptation options available to increase urban space resilience to flooding.

## 3.2. Research questions

From the introduction, the problem statement, and the literature review, it can be seen that combining soft adaptation measures with hard adaptation appears to be optimal. Limitations in understanding how to utilize soft adaptation best represent the biggest barrier to implementation. This applies to the field of interest in the research, flooding defense in the urbanized environment. The main research question follows:

- *How can soft adaptation measures influence flooding resilience in an urbanized environment?*

Flooding resilience in the urban environment is understood as the capability of the urban environment to withstand and/or recover quickly from flooding-induced damage (Derived from IBM 2024. Answering the research question directly is unfeasible due to the research gaps identified in the literature review. As such, the following set of "sub-research questions" is intended to assist with the task by preparing the path and contextualizing information.

1. What constitutes a soft-adaptation measure?
2. What types of soft adaptation measures are commonly used for flooding?
3. What are the advantages and disadvantages of each of the soft measures?
4. What is the interaction with other adaptation measures?

The research and sub-research questions act as the guide for the entire process and mark the internal subdivisions within the research project.

## 3.3. Research framework

The research structure for the project is divided into two large parts:

1. Theoretical stage: The first part of the project utilizes mainly sourced information from academic sources. Sub-research questions 1 and 2 are answered in this stage.
2. Qualitative stage: The second part of the project utilizes mainly information gathered from experts through one-on-one interviews. Sub-research questions 3 and 4 are answered in this stage.

The objective of the two-stage approach is twofold:

1. Utilize the answers from the first stage to tailor the methodology during the second stage. This ensures the information gathered from the qualitative stage is useful.
2. Contextualize the results from the qualitative stage, facilitating their interpretation. This improves the quality of the results gathered.

This approach is based on the explanatory sequential design of mixed methodology research, with some distinctions. Explanatory sequential design utilizes quantitative data gathering and analysis to better explain and research subsequent qualitative data. Figure [3.1] provides the schematic format for the thesis's overall approach.


**Figure 3.1:** Research framework for the potential research questions. From (McLeod 2024a)

Figure [3.1] shows the alignment between the strategy taken for the thesis and explanatory sequential design. The main difference between them is the utilization of theoretical data instead of quantitative data. The distinction between quantitative and qualitative does not apply to the project; the data is

purely qualitative, and the distinction is empirical (gathered from experts) or theoretical.

The theoretical stage is further split into two research sections, from here onward referred to as research "blocks". Each block is a self-contained piece centered around answering a sub-research question. The two blocks, in order of research, are:

1. First block: Covering sub-research question one (SR1). It is named: Defining soft adaptation measures (Chapter [4]). Drawing from the literature review on the topic to detect issues with the current definition of soft adaptation. A new definition is then developed. This block uses academic sources that represent the agreed center of the field.
2. Second block: Covering sub-research question two (SR2). It is named: Cataloguing soft adaptation measures (Chapter [5]). It involves the creation of a measure catalog to organize soft adaptation in flooding. The definition of soft adaptation obtained in the first block is used as the base of a second literature review. This literature review is focused on finding the soft adaptation measures used in the context of urban flooding defense. Published academic or governmental reports are the only sources of soft measures for the selection.

The qualitative stage is comprised of a singular research block, due to sub-research questions three and four being suited for simultaneous discussion. The block is:

3. Third Block: Covering sub-research questions three and four (SR3 & SR4). It concerns the costs, benefits, and interaction aspects attached to each soft adaptation measure in the flooding defense sphere. It is further split in the document into two parts, which are named: Setup for soft adaptation measure evaluation (Chapter [6]) and Soft adaptation measure evaluation (Chapter [7]).
    (a) Setup for soft adaptation measure evaluation covers the use of a semi-structured interview approach to gather both thoughts and direct comparisons from the experts on soft adaptation measures. The measures discussed are the ones cataloged in block two.
    (b) Soft adaptation measure evaluation covers the subsequent analysis of the data gathered during the setup. The comparison data provides the main foundation for the unweighted scoring matrix. The thoughts and insights from experts provide context and information on the interaction aspects between the measures. The qualitative analysis also validates and provides additional context on the results of the first two blocks.

The theoretical blocks of the research provide a foundation that directs the approach taken during the qualitative block, concerning empirical information gathered from field experts. This information is the origin of the datasets used to answer the main research question of the thesis. A more detailed decomposition of the research blocks can be seen in Figure [3.1].

Internally, the blocks are self-contained units. The methodology section is split and included directly into the respective research blocks. It is therefore not grouped into a singular chapter and not discussed in detail prior to the block, to avoid needless repetition. Justification for choices made is also excluded from this chapter and included in each research block, when deemed relevant. Results are given for each block, but the explicit answers to the sub-research questions are reserved for the conclusion chapter.

Additionally, there are some extra chapters in the document that are not explicitly named in Figure [3.1]. They are:

1. The literature review: Covering all the theoretical research. It includes a review of adaptation and mitigation, the paradigm of soft adaptation, previous attempts at cataloging and analyzing soft adaptation, and the flood defense governance structure used in the Netherlands.
2. The discussion: Providing a review of all the results obtained in the research blocks. It also includes an overview of their utility in the field and a review of assertions found in the literature review. Lastly, limitations of the entire research project are discussed.
3. The conclusion: The last chapter of the document provides a detailed response to every research question. The sub-research questions are covered individually. Their combined results form the base upon which the main research question of the project is answered.

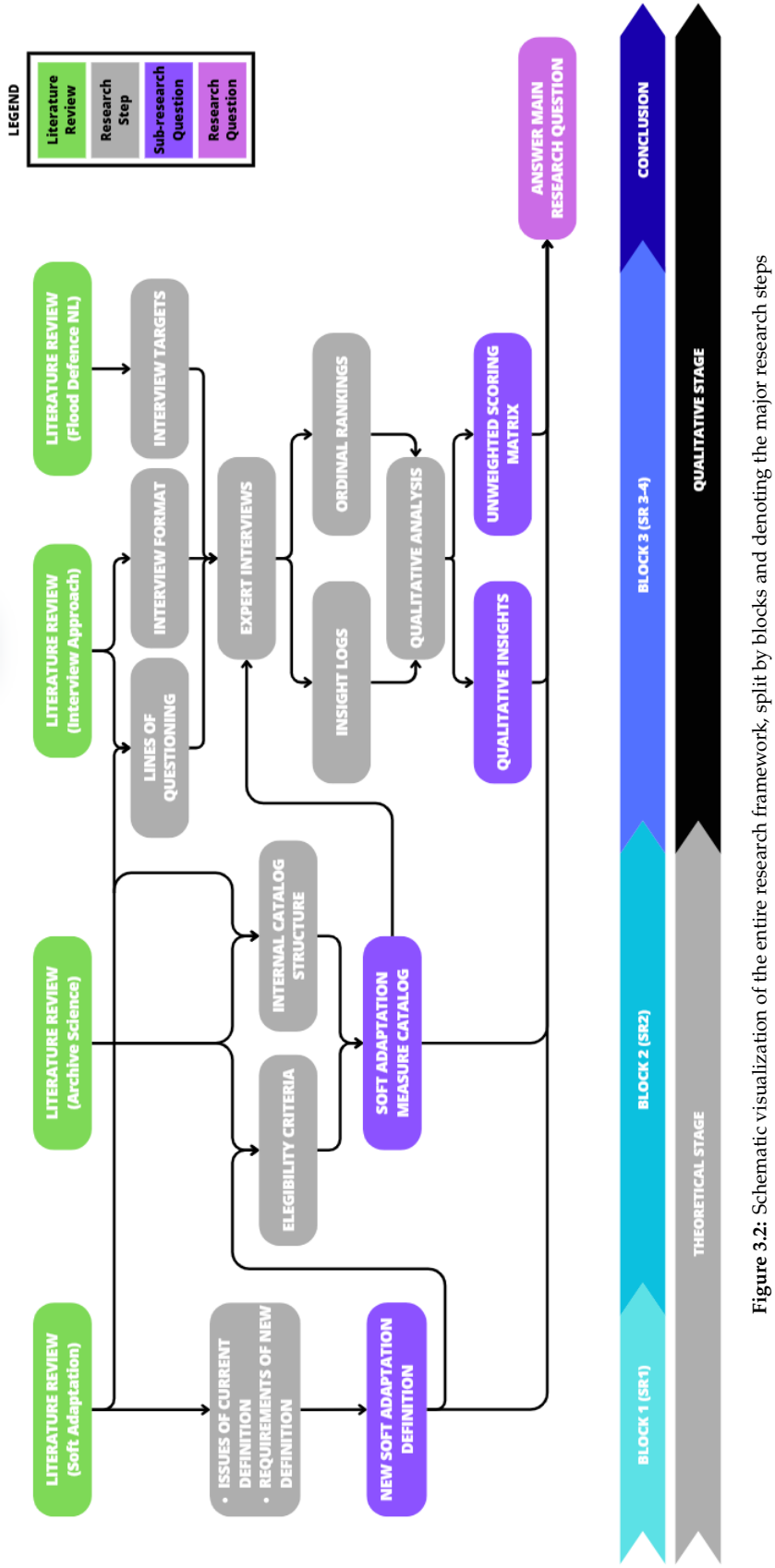



**Figure 3.2:** Schematic visualization of the entire research framework, split by blocks and denoting the major research steps

# 4

# Defining soft adaptation measures

This chapter encompasses the entire process surrounding the answering of the first sub-research question.

1. *What constitutes a soft adaptation measure?*

The chapter is split into three sections. Section [4.1] covers the challenges arising from the current definition, with a direct follow-up on the goals that a new definition must accomplish. Section [4.2] covers the creation of a new definition for soft adaptation measures, together with supplementary definitions aimed at aiding comprehension. Section [4.2] answers SR1 and closes the chapter.

## 4.1. Defining soft adaptation

The following section delves into the process undertaken to provide a solid definition of what constitutes a soft adaptation measure. The following subsections begin with a list of the current challenges and shortcomings detected in the commonly used current definition, with a brief discussion of what the new definition ought to solve.

### 4.1.1. Current challenges

The literature review shows a significant number of problems that have made soft adaptation measure adoption challenging within the policymaking sphere. Among the key apparent issues are the bias towards infrastructure due to its proven record, the difficulty of describing adaptation measures through currently used analysis systems, and their strong emphasis on citizen-government co-production. Literature also indicates that some of these issues share a common root: their definition. Two issues are covered:

1. The definitions provided by Sovacool (2011) and Hallegate (2009) are subjective and open to interpretation (Dolšak and Prakash 2018). It is challenging to consistently analyze soft adaptation measures if each new paper must provide a personal interpretation of their definition. Academic research on the topic shows low consistency regarding soft adaptation measures for this reason.
2. The definition is too broad and encompasses too many measures. It is a derivation of the first issue. The transformation of the topic from its original design field has resulted in the inclusion of too many measures on the soft adaptation paradigm. Nature-based solutions are a common example. Their inclusion exacerbates the bias towards infrastructure-based adaptation and further alienates social and institutional measures in adaptation analyses, visible in Cai et al. (2024) and Moon et al. (2024).

### 4.1.2. Definition goals

From the current challenges, it becomes easier to discern what a new definition ought to accomplish. Besides providing a solution to the previously mentioned issues, it must also assist with the overarching goal of the research. Some important objectives worth remarking on include:

- It must restrict soft measures to those that focus on administrative, social, or informational systems. These measures have been consistently sidelined in favor of measures that involve heavy infrastructure, whether natural or artificial.
- It must rely on clearer rule-sets to limit the impact of subjectivity within group inclusion of measures. Clear boundaries will increase cohesion between separate pieces of research and allow academia to move forward as a whole.
- It should adhere to the current academic conceptualization of soft-adaptation. This is to minimize confusion and act as a consolidating point for the field to move onward.

## 4.2. New definitions

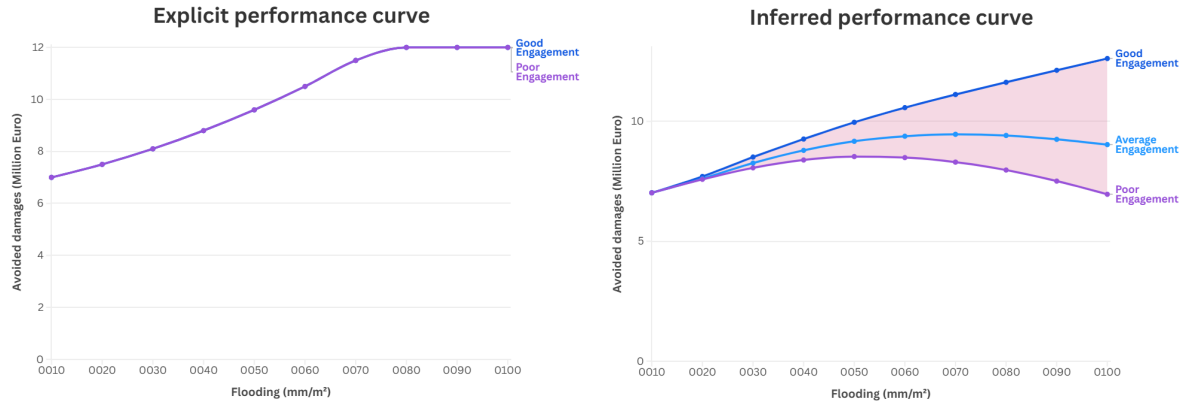
With the challenges and goals covered, this section provides the definitions of hard and soft adaptation measures. They act as the working base for the rest of the research. These definitions have been crafted with the previous information ( challenges and goals) in mind. They are intended to consolidate the field and enable academia to consistently categorize measures within either of the adaptation paths.

Two supplementary definitions are covered first. They relate to the performance of adaptation measures during climate-induced events and the predictability of this performance.

**Definition 4.2.1 (Explicit performance)** *An adaptation measure is said to show an explicit performance when its performance can be predicted before implementation. End-user engagement with the measure has no significant impact on the performance or its maximum theoretical design capability.*

**Definition 4.2.2 (Inferred performance)** *An adaptation measure is said to show an inferred performance curve when its performance is unpredictable prior to implementation. Increased and positive engagement increases both the performance and the hidden maximum theoretical design capability of the measure. Low or negative end-user engagement hinders performance and reduces the hidden maximum theoretical design capability.*

Figures [4.1a] and [4.1b] show examples of explicit and inferred performance curves, respectively.




**(a)** Explicit performance curve

**(b)** Inferred performance curve

**Figure 4.1:** Types of performance curves

Figure [4.1a] provides a visual example of an explicit performance curve. Numbers are indicative only. The avoided damages increase linearly with flooding up until a clearly defined limit, after which the measure does not provide any further damage avoidance. This limit is the maximum theoretical design capability, and in this example, it sits at a flooding of 80 millimeters of water per square meter. The quality or quantity of end-user engagement has no impact on the performance of the measure or the maximum damage avoidance. The actual performance of the measure will strongly match the prediction curve.

Figure [4.1b] displays an example of an inferred performance curve. Numbers are once more, indicative only. The avoided damages vary substantially depending on the quality and quantity of the

engagement. Good end-user engagement improves the measure's performance and raises the hidden theoretical maximum design capability. Average or poor end-user engagement can still yield benefits in low-flood situations, but the hidden maximum will be lower. Performance might even decrease in high-stress events with sub-standard engagement. The actual performance of the measure will sit somewhere in the pink-shaded area and only be fully known after implementation.

The final definitions for the paradigms of soft and hard adaptation measures follow hereunder:

**Definition 4.2.3 (Hard adaptation measure)** *Hard adaptation measures comprise those centered around infrastructure, whether natural or artificial.*

Hard adaptation measures usually incur large initial capital investments and provide a consistent benefit. Their performance generally follows an explicit curve [4.2.1]. They tend to show low adaptability to sudden changes in climate change predictions. Hard adaptation requires little to no interaction between the infrastructure or the government and the end-user who reaps the benefits. Hard adaptation adheres to the mentality of bending the environment to societal needs.

**Definition 4.2.4 (Soft adaptation measure)** *Soft adaptation measures include those that rely on social, institutional, educational, or economic systems.*

Soft adaptation measures generally incur low initial capital investments, but require sustained investment or recurring support expenses. Their performance usually follows an inferred curve [4.2.2]. They usually present high adaptability to sudden changes in climate change predictions. Interaction between the measure, the government, and the end-user is either mandatory or strongly required to reap the benefits. Soft adaptation adheres to the mentality of changing societal approaches to environmental needs.

**Definition comparison**
The following table (4.1) provides an itemized description of the definitions, in order to assist with potential confusion and compare the two paths side-by-side. References are included when applicable, if the concept has not been derived during this research.

| Path | Hard Adaptation | Soft Adaptation |
|---|---|---|
| Focus | Natural or artificial infrastructure | Social, institutional or policy systems |
| Investment | Large (Sovacool 2011) | Low (Sovacool 2011) |
| Performance | Explicit (Predictable) | Inferred (Unpredictable) |
| User Engagement | Minimal (Dolšak and Prakash 2018) | Strongly required (Dolšak and Prakash 2018) |
| Flexibility | Low (Sovacool 2011) | High (Sovacool 2011) |
| Lock-In | High (Sovacool 2011) | Low (Sovacool 2011) |
| Centralization | High (Sovacool 2011) | Low (Sovacool 2011) |
| Mentality | "Adapt nature to us" | "Adapt us to nature" |
| Governance | Top-Down (Dolšak and Prakash 2018) | Co-Produced with end-users (Dolšak and Prakash 2018) |

**Table 4.1:** Itemized descriptions of the two paths available in Adaptation.

The distinction between soft and hard adaptation is binary; measures either are part of one paradigm or the other. It is therefore possible that a complex adaptation measure is made up of a subset of simpler systems. These sub-systems will be part of either soft or hard adaptation. The complete measure can be grouped in either position, depending on which subsystems are central to the overall measure.

**What exactly constitutes a soft-adaptation measure?**
Adaptation measures are said to be part of the soft paradigm when they rely on social, institutional, educational, or economic policy. Their performance cannot be predicted before implementation due to their interaction with the end-user, which is either mandatory or strongly required, and the nature of which has an impact on their utility. It adheres to the mentality of "changing societal approaches to environmental needs".

# 5

# Cataloguing soft adaptation measures

This chapter focuses on answering the second sub-research question.

2. *What types of soft adaptation measures are commonly used for flooding?*

Section [5.1] opens the chapter and covers the goals and challenges that dictate the requirements of the finalized catalog. These considerations form the basis for the methodology approach taken when designing the catalog, which is discussed in section [5.2]. The results, displaying the finalized catalog, are included in section [5.3]. Section [5.4] provides the explicit answer to SR2 and closes the chapter.

## 5.1. Catalog challenges and goals

Subsection [5.1.2] covers all the information related to the thought process surrounding the creation of the catalog, starting with the goals the catalog aims to achieve, based on the research questions that must be answered. Subsection [5.1.1] covers the main challenges to overcome when designing the catalog.

### 5.1.1. Current challenges

Prior to designing the catalog itself, the potential challenges surrounding the topic must be considered. The literature review brings up several challenges, and two of them are particularly poignant when addressing the second sub-research question.

1. To the knowledge of the authors, there are no catalogs focused on soft adaptation measures, only on general adaptation (Noble et al. 2014; Hallegatte 2009).
2. There is no consensus on how to categorize adaptation measures (Noble et al. 2014), the problem appears to extend to soft adaptation measures.

Due to the increased focus on soft adaptation within this research, any current catalog that has not addressed the underlying challenges mentioned, such as the one from the IPCC fifth report (2014) or the ones from Hallegate (2009) or Baills et al. (2020), is not well-suited for this research.

### 5.1.2. Catalog goals

Having a catalog that adheres to the needs of the research is relevant as the catalog is a central building block of the subsequent research. The goals of the catalog are clearly defined by the second sub-research question shown in the opening of the chapter. Answering this question is relatively simple. The objectives of the catalog, therefore, become the following, in order of importance:

1. Find out what soft adaptation measures are commonplace in flood defense within the urban environment.
2. Create a system to categorize them consistently. This objective is more generalized and comes together with the creation of any catalog.

There is extensive theory discussing approaches to cataloging within archival sciences, with special importance given to the concepts of Provenance (SAA 2025) and Original order (Office 2024). The utilization of these concepts to guide the cataloging process will provide a suitable approach that meets the goals and addresses the current challenges. Additionally, as a standardized cataloging approach, it will open the possibility to expand the catalog in the future if new insights are discovered.

## 5.2. Methodology

Subsection [5.2.1] discusses the key theoretical concepts upon which the cataloging approach is based. Subsection [5.2.2] covers the selection criteria that measures must adhere to in order to qualify for inclusion. Subsection [5.2.3] covers the grouping criteria within the catalog.

### 5.2.1. Classification theory

When utilizing the word "catalog" in this project, it refers to the practice of organizing information within an archival format from which it can be easily retrieved. This ease of retrieval is achieved through standardized classification that assists any user in locating items or information within. There is extensive theory surrounding this topic in the form of information, library, and archival Sciences. The main aspects of relevance for this research involve the concepts of Provenance and Original Order (SAA 2025; Office 2024).

- The concept of provenance refers to the history of an item (Office 2024; SAA 2025). In archival sciences specifically, it includes the origin and intended purpose of the item. If there is no provenance, it is recommended to generate an artificial collection based on the subject matter (Office 2024).
- The concept of original order is a derivation from the concept of provenance, and refers to the idea that items should not be separated from their original groupings, when possible (Office 2024).

Both of these topics provide insights that justify decisions taken both when selecting data and when categorizing it. They are revisited, when relevant, in the following subsections.

### 5.2.2. Selection criteria

The selection criteria include the requirements mentioned hereunder, with some observations worth mentioning:

1. They have to relate to flooding protection and/or resilience, whether directly (targeting it specifically) or indirectly (targeting general resilience but with an application to flooding).
2. They must appear in an existing adaptation catalog. Additionally, they must appear in an academic source (either as the topic of study or in a simple mention) or an institutional report.
3. They must adhere to the definition provided in the previous block (4.2.4). Complex measures encompassing a subset of hard and soft systems can be included if the soft systems are considered central to the overall measure.

The first two criteria relate to the concept of provenance. Items must originate from the same areas of research or engineering to facilitate further classification and ensure that the catalog remains useful and concise. In simple terms, it means that they must have the same context: soft adaptation measures that target flooding in the urban space.

The third and last criterion concerns the concept of original order. Many measures within the flooding adaptation field concern a mix of hard and soft adaptation. If measures are split to achieve this, contextual information is lost. To illustrate this concept, the reader is requested to consider the measure of warning systems. Warning systems are generally considered to include two components:

1. The physical infrastructure that gathers the data (hard adaptation)
2. The information framework that develops the warning and divulges it as directed (soft adaptation).

Following the concept of the original order, it would be detrimental to split warning systems down into these two building blocks, as significant context is lost. So it is included in the catalog even though

it does not meet the soft adaptation definition entirely, as the information framework is a core aspect of the warning system.

If an adaptation measure adheres to all three requirements mentioned, it qualifies for the catalog and is categorized based on its qualities. The internal grouping criteria are discussed further in the following subsection.

### 5.2.3. Grouping criteria

Once all qualifying measures have been selected, the next step is to find a way to categorize them in a standardized way. This is made difficult due to an issue commonplace within the field that relates to the complete disconnect individual academic sources display between themselves. The research gap section discussed the problem, and the research aims to solve the issue by once more applying archival theory as an underlying justification for the system choices.

The topic of data classification represents a very common problem within information sciences, and significant research has been conducted to provide ways to solve it. The research has centered around two main theories that give different approaches to solving classification challenges. They are:

1. Request-based classification: Categories are influenced by the anticipated requests of the classification user (Soergel 1985). This approach makes the location of information easy but carries significant work due to having to predict future usage.
2. Content-based classification: Categories are influenced by the main content topics of the documents (Soergel 1985). This approach eases the categorization itself but can make the location of information by an uninformed end-user difficult.

Both of these approaches are relevant for the research. Request-based classification is the ideal approach, since it explicitly links end-user needs with classification structure, but the challenges present within the literature, namely the lack of consensus, make it unfeasible to rely solely on it. Therefore, content-based classification will need to be used to further categorize measures within the catalog.

#### Request-based classification

The core aspect of request-based classification lies in determining the needs of the hypothetical end-user that will be searching through the catalog (Soergel 1985). The categories used should adhere to the following aspects:

1. They should be common within the fields relevant to the research. If a categorization is seldom used, no end-user will understand how to approach it.
2. They should lie at the overview level. Since the end-user will likely be familiar with the categorization, it eases the start of the information-locating process.

Within the adaptation field, there is a categorization that fits both of these requirements. This categorization is general in nature and divides adaptation into three categories: Structural, social and institutional Noble et al. 2014. There is no official name for this categorization; this research will, from now on, refer to it as the external categorization, owing to its origin from outside this research.

Concerning the categories within the criterion itself, there are three potential options:

1. *Structural/Physical*: Adaptation options in this category comprise measures that are discrete, with clear outputs and outcomes that are well defined in scope, space and time. Examples include structural measures, and the use of ecosystems.
2. *Social*: Adaptation options in this category directly target end-users and actively engage them. Examples include educational, informational and behavioral measures.
3. *Institutional*: Institutional adaptation measures comprise those that either engage the end-users through a legislative body such as the government or target the government itself. Examples include economic incentives, legislation or government policies.

The structural/physical category encompasses adaptation measures defined as hard, and it is therefore not used in the final catalog. The other two categories include all measures deemed to adhere to the soft paradigm. They are, however, quite general and with significant overlap (Noble et al. 2014). Further categorization is needed.

**Content-based classification**
Content-based classification is much simpler to understand, as information is grouped purely on the predominant content present within it (Soergel 1985). Categories usable in this approach should adhere to the following needs:

1. They should be useful and relevant within the field of research.
2. They should be immediately obvious to an uninformed end-user. Since there has been no real consideration on what future requirements will be, it is best to assume every end-user will be uninformed.

As discussed in the IPCC synthesis report (2014), the content-based categories used in it present significant overlap and include plenty of measures not used in flooding adaptation. Therefore, new categories have been artificially created during this research to better suit the flooding adaptation field. As the content-based classification scheme is an artificial creation of this research, it is defined hereunder:

**Definition 5.2.1 (Domain of action)** *The domain of action of a measure refers to the specific area or scope that the measure has influence over.*

Categories are drawn by reviewing the function of the adaptation measure and which aspect of flooding adaptation it targets. An example is zone management, which, either by regulating or by assessing vulnerabilities, centers around adapting and better understanding the urban space. Another example is evacuation, which can take plenty of forms and centers around the quick displacement of people and/or assets.

The domain of action is also denoted as the internal categorization, due to the categories being created during this research.

### 5.2.4. Cataloguing process
Having covered all the individual building blocks, the entire cataloging process can be explained. Figure [5.1] provides a visual representation of the process, from identification to the final internal catalog placement.

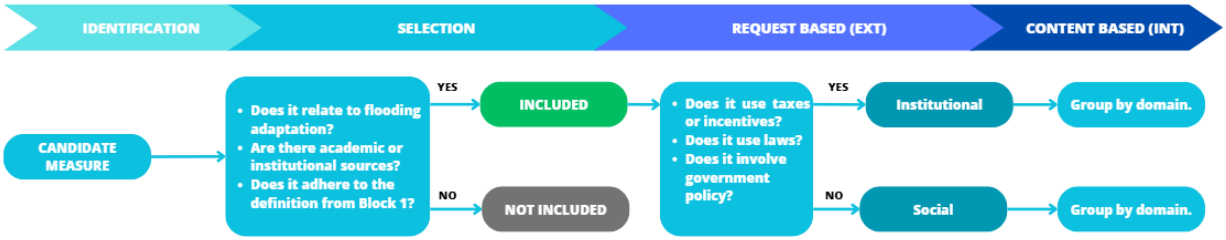



**Figure 5.1:** Schematic cataloging process.

## 5.3. Results
This section displays the results of the cataloging process. Subsection [5.3.1] covers the domains of action found and used for the cataloging process, while subsection [5.3.2] provides a visualization of the entire finalized soft adaptation measure catalog.

### 5.3.1. Domains of action
This subsection is divided into the two external categories drawn from the IPPC fifth report (2014). Within each subdivision lie the domains of action included in each. An explanation for their meaning and examples of measures within each is included.

**Social category**
As explained in subsection [5.2.3], the social category includes measures that directly target the end-user and do not use any regulatory, economic or legislative tools. There are three internal spheres of influence relevant to the flooding adaptation field:

1. Educational: Measures that target educational aspects are difficult to place in the timeline due to their effect being engaged constantly. Educational measures come in two main forms: Practical and Emotional. Examples of emotional education include mental health support and/or preparation (Foudi, Osés-Eraso, and Galarraga 2017), while practical education examples include information campaigns (Dufty 2021) and event drills.
2. Warning Systems: Measures in this sphere revolve purely around providing active warning information prior to climatic shock events (Sustania and C40 2016). They provide and update accurate expectations for the event in order to facilitate further decision-making and/or measure activation. A threat monitoring system or an active early-warning system would be suitable examples (Sustania and C40 2016).
3. Evacuation: This sphere comprises the adaptation measures intended to streamline and/or improve the temporary relocation of threatened people or assets during a climatic shock event (Kolen 2013). Evacuation can take lots of forms, and proper utilization of these measures allows for flexibility in adaptation strategies and a significant reduction of damage when crisis events overpower flooding defenses (Kolen 2013). Some examples of measures in this topic include evacuation routing or emergency logistical protocols (Bernardini 2022).

**Institutional category**
Measures in the Institutional category engage the end-user indirectly, through legislative or regulatory tools, oftentimes done by the governments. Measures targeting the government itself are also part of the institutional category. For this category, there are once more three domains of action considered relevant in the flooding adaptation field:

1. Regeneration: Regeneration in the context of soft adaptation measures aim to stimulate the regeneration of the affected area, and target either human or natural assets (Sustania and C40 2016). The regeneration process can be economical, cultural, institutional, or environmental. Some examples include disaster recovery plans or large insurance protocols (Sustania and C40 2016; Ebi and Semenza 2008; Dolšak and Prakash 2018).
2. Zone Management: This domain of action focuses on proactively managing the urban space. There are plenty of ways to do this, but the most common ones involves zone assessments aimed at generating information that quantifies their risk (Sustania and C40 2016). The information obtained informs subsequent policies that revise building regulations to adapt to the detected risks (Kazmierczak et al. 2020). Examples include risk-zone assessments, vulnerability reports, land-zone planning, and land-use policies
3. Administrative: Measures within the administrative domain of action aim at reducing over-dependence on specific people and/or assets, which carry potentially disastrous risks during crisis events if they malfunction. A recent and noticeable example of this over-dependence can be seen in the Valencia floods, where the emergency messages calling for evacuation were delayed for several hours due to chaotic government communication, leading to an elevated casualty rate (Williamson 2025). This is most often done through information sharing guidelines and back-up policies (EMRIC 2025; Ley et al. 2014).

**General measures**
The last category of soft adaptation measures used in the catalog comprises a special set of measures that cannot be properly categorized within the other two categories. Due to their more unique nature, they are included in a general category. Only one domain of action is considered:

1. Evaluation: Evaluation encompasses all the measures that aim to study and monitor the effectiveness and weaknesses of other soft measures (EEA 2025). Evaluation is done constantly since it targets every other measure in the catalog. Examples include effectiveness assessments and digital simulations.

### 5.3.2. Measure catalog

With the methodology covered, Table [5.1] provides the generated Soft Adaptation Measure catalog, with a restrictive focus on measures concerning flood adaptation. The catalog presented hereunder is non-exhaustive, but it encompasses the most common aspects of flooding adaptation aligning to the soft paradigm.

| Social | | | | |
|---|---|---|---|---|
| Domain of Action | Description | End User | Examples | Sources |
| Evacuation | - Plans for large scale evacuation and temporary relocation of human or physical assets. | - Everyone | - Evacuation routing<br>- Emergency logistical protocols | (Kolen 2013)<br>(Bernardini 2022)<br>(Noble et al. 2014) |
| Warning Systems | - Systems that provide warnings prior to catastrophic events.<br>- Systems that provide damage predictions. | - Everyone (Warning system)<br>- Administration (Damage predict) | - Early warning system<br>- State-wide alarms on phones | (Sustania and C40 2016)<br>(Noble et al. 2014) |
| Educational | - Programs and policies that increase public knowledge about event dangers and correct behaviour during crises. | - Everyone | - Event Drills<br>- Information Campaigns | (Foudi, Osés-Eraso, and Galarraga 2017)<br>(Dufty 2021)<br>(Noble et al. 2014) |
| Institutional | | | | |
| Domain of Action | Description | End User | Examples | Sources |
| Regeneration | - Policies that mitigate aftermath issues.<br>- Policies that stimulate asset regeneration after extensive flood-induced damage.<br>- Policies relocating assets permanently after stress events | - Everyone | - Insurance Schemes<br>- Aftermath-updated healthcare protocols<br>- Relocation | (Sustania and C40 2016)<br>(Ebi and Semenza 2008)<br>(Dolšak and Prakash 2018)<br>(Noble et al. 2014) |
| Zone Management | - Systems for assessing risks faced by urban zones.<br>- Subsequent regulations enforcing rules on them. | - Everyone (Building restrictions)<br>- Administration (Zone assessments) | - Zone risk assessment<br>-Zone planning<br>- Building restrictions<br>- Safety code requirements | (Kazmierczak et al. 2020)<br>(Sustania and C40 2016)<br>(Noble et al. 2014) |
| Administrative | - Policies intending to reduce malfunction risk caused by over-dependence or over-importance of individual assets and/or people. | - Administration | - Backup policies<br>- Regulations on Information sharing<br>- Shared responsibility model | (Ley et al. 2014)<br>(EMRIC 2025)<br>(Noble et al. 2014) |
| General | | | | |
| Domain of Action | Description | End User | Examples | Sources |
| Evaluation | - Analysis protocols to determine what works and what does not.<br>- Error detection and improvement protocols. | - Administration | - Post-event analyses<br>- Measure testing<br>- Digital simulations | (EEA 2025) |

**Table 5.1:** Soft adaptation measure catalog, restricted to flooding

As discussed in the methodology, measures are categorized first on the external categories and subsequently grouped into domains of action, shown in the first or leftmost column. A brief and itemized description of the domain of action is provided in the second column. In the third column, there is a list of the potential end-users that the measures in the domain of action can target. The fourth column covers some specific examples of soft adaptation measures that are included in the domain of action. Lastly, references to where the measure has been extracted from are provided.

## 5.4. What types of soft adaptation measures are commonly used in flooding?

For flooding, soft adaptation measures can be categorized into one of seven general groups, each based on a different strategy but all aimed at increasing the flooding resilience in one way or another. They include:

1. Warning Systems: These measures focus on providing warnings and predicting damages before crisis events, intending to reduce damages
2. Zone Management: These measures focus on the assessment of vulnerable areas and the development of subsequent regulations to reduce their vulnerability.
3. Evacuation: These measures focus on the movement of people and assets away from dangerous areas during crisis events. They aim to save lives and limit damage.
4. Administrative: These measures focus on the information flow and governance structure within governmental organizations. Their goal is to reduce over-dependence and, by extension, limit additional chaos-induced damage.
5. Regeneration: These measures aim to stimulate the reconstruction and regeneration of damaged areas after crisis events. They aim to speed a return to pre-event normalcy.
6. Educational: These measures focus on disseminating knowledge to increase end-user knowledge. They aim to limit damage by fostering self-reliance and better engagement with other measures.
7. Evaluation: These measures review and test the implementation of other measures, to ascertain what works and what does not. They aim to increase the effectiveness of other measures.

# 6

# Set up for soft adaptation measure evaluation

The third and final block of the thesis revolves around answering the second pair of sub-research questions.

This chapter covers the former and focuses on the data gathering for the third research block, utilizing semi-structured interviews with professionals from specific fields, with interactive aspects intended to stimulate discussion. The next chapter will revolve around the utilization of the data obtained in Third Block A to answer the questions.

This chapter begins with an exposition of the challenges present at this stage of the process and the subsequent goals that guide the research. The methodology outline follows right after, covering the interview and specific question designs first, and continuing with the selection of the target audience of interviewees and the ethical aspects of relevance. After the data gathering methodology follows a section follows displaying the results from the interviews, in the form of the ordinal rankings.

## 6.1. Challenges and objectives of data gathering

The following section provides an overview of the thought process behind the interviews utilized in the data-gathering part of the project. The first part of this section covers current challenges to consider when designing the data-gathering approach. The second subsection involves an exposition of the goals of the data-gathering part of this block, based on the needs of the research questions.

### 6.1.1. Current challenges

The literature review provided some significant challenges that strongly impact the research around soft-adaptation measures. Some of them have already been addressed in the previous two blocks, but there are a couple that still present a significant challenge and must be addressed:

1. Data on soft adaptation measures is limited. Papers consistently regurgitate generalized statements and never provide specifics on how the measures perform.
2. When data is gathered, it is usually done so in a hyper-specific manner with individual case-studies, something problematic as soft adaptation measures are not well described by traditional quantitative analysis methods due to their contextual connotations. Data on soft adaptation measures from these sources is therefore of little utility as no lessons can be exported to the general field.

From the challenges, it is apparent that existing sources of data are limited, both in quantity and in utility. As such, it becomes optimal to shape the data-gathering process around research methods that facilitate data collection from the field, such as interviews (McLeod 2024b). Interviews present a solid option that can be tailored to try to meet the goals while accounting for the challenges, thanks to their elevated customization options.

### 6.1.2. Data gathering goals

The itemized goals for the data gathering encompass the following, with some brief explanations for each:

1. Gather data on how soft adaptation measures perform in multiple categories. Hard measures must also be included in order to have a common anchoring point and provide some comparison.
2. Gather data on the unique aspects of utilizing soft adaptation measures. Many of the soft adaptation measures provide additional benefits or carry different aspects than traditional hard adaptation.
3. Gather data on how and how much impact soft adaptation measures can have on other adaptation measures, including hard measures. A core aspect of the advocacy behind their increased usage relies on the argument that they have the potential for significant positive impact in other measures, particularly hard adaptation.

Overall, the first goal is purely aimed at assisting with answering the first sub-research question of the pair and is answered best by quantitative data. The third goal is fully focused on assisting with the answer to the second sub-research question, and benefits from either quantitative or qualitative data. The second goal acts as a hybrid middle point intended to provide additional insight that the other objectives might miss, something best covered by qualitative data.

## 6.2. Methodology

This section delves into the specifics of the research format, that being the design of the interviews with field professionals. The first subsection provides a general overview of the interview format and the unique aspects of it, with justification for the choices made. The second subsection covers the specific lines of questioning derived and the reason for their inclusion. The third subsection concerns the targets for the interviews. The fourth and last subsection provides a brief example of the expected results.

### 6.2.1. Overall approach

Interviews are a commonplace research methodology for qualitative research (McLeod 2024b), especially when data in academic sources is limited, whether that limitation is in quantity, quality, or context. There is a general agreement that the approach taken when designing and/or running the interview can significant impact on both the resulting data obtained, which can range from quantitative to qualitative, and the subsequent options available when discussing and/or analyzing the results.

Traditionally, interviews are defined along a spectrum ranging from structured to unstructured (Blackman and Funder 2002; Bailey 2008; Knott et al. 2022). These two approaches provide significant benefits and carry significant costs, and while they both would provide valuable data that aligns with the data gathering goals, they each fall short of the desired in significant ways. Structured interviews gather significant quantitative data, but do not provide any real context for the data gathered, something that has been shown to carry significant relevance in the topic of soft adaptation. Unstructured interviews do not fare much better either, as the resulting data is completely qualitative; This does not allow for comparison between datasets, and attempts to provide generalized statements are fruitless.

In the middle of the spectrum lies the logically named semi-structured approach to interviews. There are no exact rules for semi-structured interviews, as they encompass any hybridization that lies between the two extremes discussed above (Knott et al. 2022). But generally speaking, semi-structured interviews adhere to the following guidelines:

1. There is a combination of predetermined and spontaneous questions adhering to a framework.
2. The order of questions is flexible.

Semi-structured interviews present strong advantages as they effectively combine the strengths of both structured and unstructured interviews(Knott et al. 2022). The interview adheres to a framework that facilitates the subsequent statistical analysis of the data and provides credibility to the results. At the same time, it allows for some deviation, which makes the introduction of new insights and contextual nuance possible (Knott et al. 2022). On the other hand, they also require significantly more

preparation work as the framework must account for potential deviations, and questions must be clear. Additionally, the interviewer must be able to balance the redirection of the conversation if it deviates too much from the stimulation of personal experience.

An additional remark concerns the possibility of tailoring the interview as much as desired. The potential in semi-structured interviews is significant, as the balance can be moved as much as needed. The interview should be tailored to the requirements of the research (Knott et al. 2022).

The strong benefits added to this flexibility when it comes to the design make semi-structured interviews the optimal choice to employ for this research. The possibility to gather both quantitative and qualitative data will prove extremely useful. The initial rigidity and overall consistency will allow for generalized insights to be obtained, while the potential for deviation will enable the gathering of contextual data that will help with understanding soft adaptation measures better.

**Overview**

Figure 6.1 provides a visual explanation of the interview approach spectrum, with some key aspects of each approach that warrant a mention. Notice the quantitative and qualitative axis that lies underneath the approaches, marking the overall results that a properly conducted interview will provide.

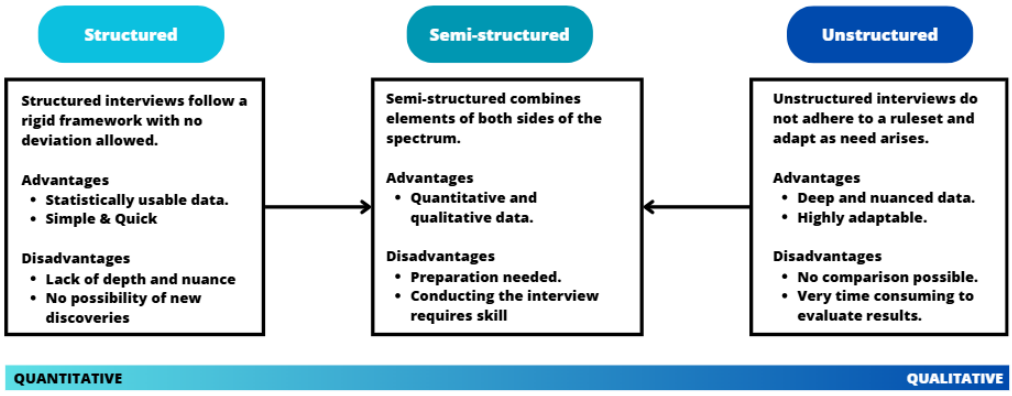



**Figure 6.1:** Interview approach spectrum.

As mentioned previously, the preference for the semi-structured interview framework comes from the possibility of mixing and matching both structured and unstructured frameworks. This mixing of a structured and unstructured interview must be carefully considered. The interview framework and questions must be tailored to provide the desired type of data in the correct amount, something challenging in this project, as both qualitative and quantitative data are of little value when separated. Quantitative data cannot be fully understood without context, and quantitative data cannot be exported to new contexts.

### 6.2.2. Interview format

The interview framework will have some rigid sections, responsible for providing data that can be compared between interviews, and some open sections, where the interviewees will feel free to share more nuanced and contextual data based on personal experience.

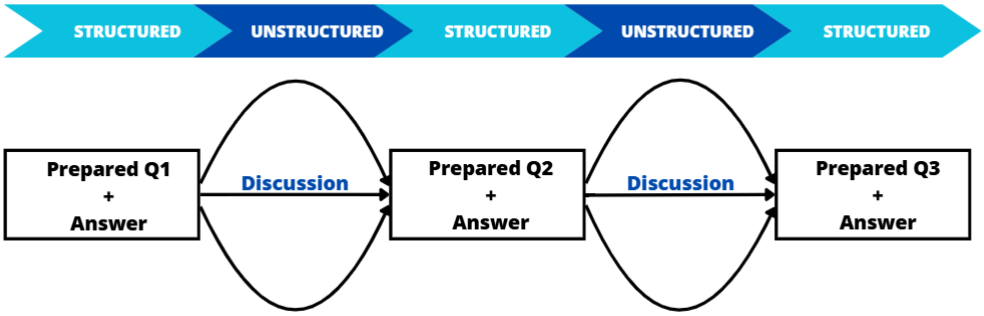



**Figure 6.2:** Proposed interview format denoting structured and unstructured sections.

Figure [6.2] shows the general interview framework. Structured sections are represented by the rectangular boxes. The answers will be standardized and, therefore, easily comparable across different interviews. The unstructured sections are represented by a set of arrows that diverge and eventually converge back in the subsequent structured section. Discussions and answers will be unique to each interview and as such take a myriad of forms. Their results will not be easily comparable between interviews.

Every interview begins with a question prepared in advance which is answered by the interviewee following a specific set of requirements. Directly after this comes an unstructured section, jump-started through follow-up questions directly related to their answers in the prepared question. This unstructured discussion can spread based on the interests or personal experiences the interviewee wishes to share . This discussion then slowly converges towards a consistent point where a second prepared question is posed, and the cycle repeats anew. If discussion during the unstructured parts drifts too far to be bridged or loses relevance to the topic, it is instead politely cut short, and the second prepared question is brought to the center to jump-start the process from there.

Overall, the interview framework will provide sets of answers that share context and are asked under similar conditions, and personal insights that are unique to each interview. Figure [6.3] provides a simplified visual example with the structured sections being comparable (same color), while the unstructured sections are unique to each interview, limited to contextualizing their answers (different color).

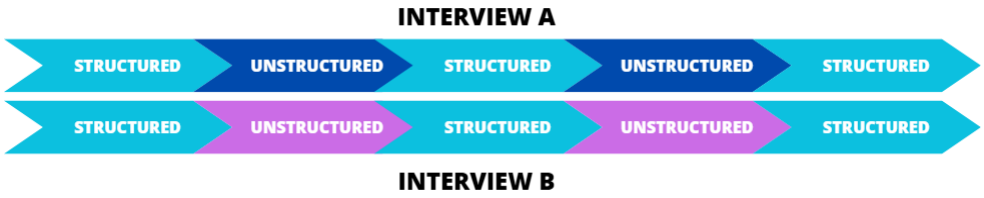



**Figure 6.3:** Color visualization of section data comparability.

### 6.2.3. Question format

As shown in subsection [6.2.2], the interview encompasses both structured and unstructured sections, and each type has completely different requirements for the format of the individual questions.

#### Structured questions

The structured interview questions consist of the interviewees ranking a set of eight physical cards (each representing one of the seven soft adaptation measure groups, plus one card for hard measures) based on a set of parameters, from worst to best. This ranking is not anchored around a fixed point and is purely ordinal. Figure [6.4] shows the cards themselves.

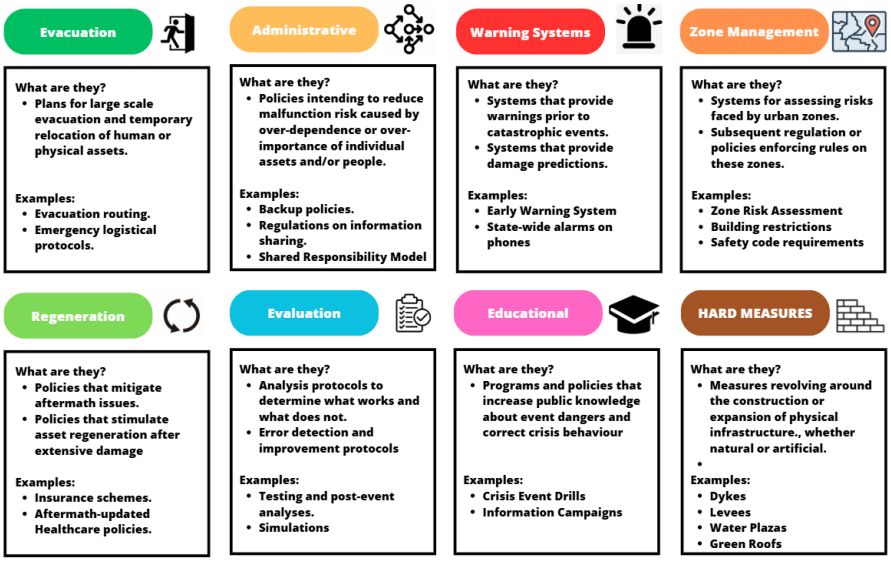



**Figure 6.4:** The eight cards representing the adaptation measures to rank. Seven soft and one hard.

The ranking is performed by placing the cards side by side from best to worst, with the possibility of additional context being introduced. An interviewee could for example put two cards one on top of another, indicating that the measures are pretty similar.

Figure [6.5] shows an example where an interviewee ranked two measures (administrative and regeneration) in the same spot in the economic cost category, as they believed them to be very close to one another, to the point that there was, to them, not a noticeable difference.

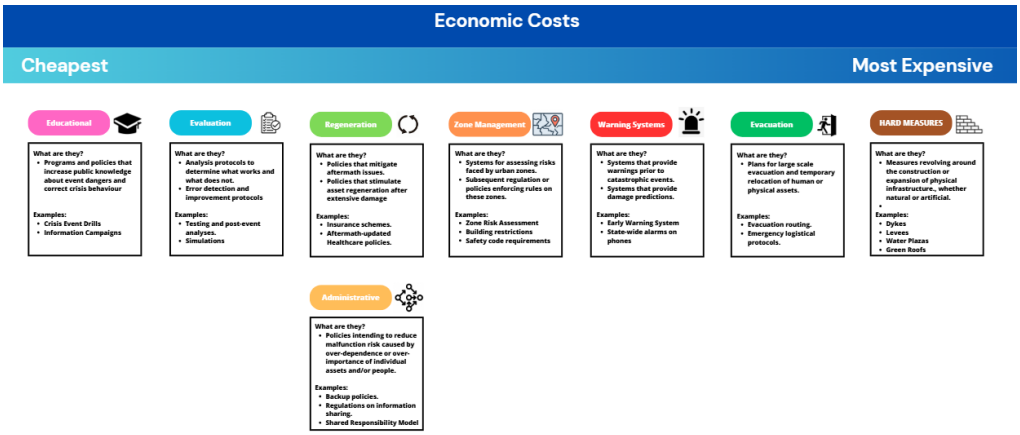



**Figure 6.5:** An example of an economical cost ranking with all 8 cards included and a vertical stack, indicating similar rank.

The physical space separating the cards can also be utilized to transmit further information: Cards that are very closely together can indicate that while there is a difference in rank, it is not a large one.

On the other hand, cards that have significant separation between one another can be taken to have a large difference between them. Additionally, interviewees can turn the cards around (physically or by marking them in the digital blackboard) to indicate that they are not confident including the measure in the ranking and would rather have it excluded for that round.

Figure [6.6] displays one such ranking where some cards are excluded from the ranking and the remaining ones have significant uneven separation between them. In this case, administrative and regeneration have been excluded from the ranking. The remaining 6 cards have been ranked with a large gap between the measures ranked in the bottom half and those in the top one, indicating that the difference between evacuation and hard measures is much larger than the ones between the rest of measures.

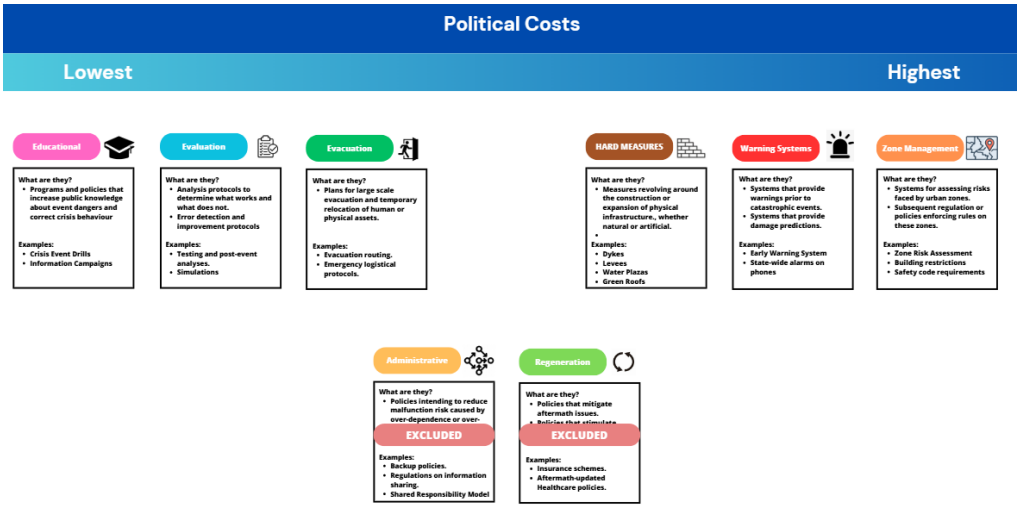



**Figure 6.6:** An example of a political cost ranking with 6 cards included and two excluded, marked with the "excluded" tag.

Lastly, interviewees could use the vertical space to indicate an additional criterion they wish to introduce: For example, an interviewee could use a vertical axis during a flexibility ranking to introduce the cost of that flexibility. Figure [6.7] shows such an example.

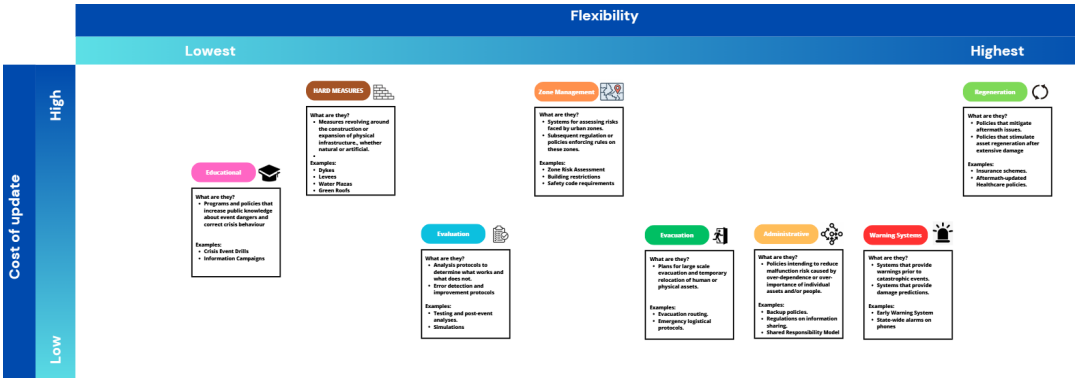



**Figure 6.7:** An example of a flexibility ranking with all cards included. An additional vertical axis describes the cost of the flexibility.

From figure [6.7] it would be seen that hard adaptation is one of the least flexible options compared to the other measures. This implies that hard adaptation is difficult to modify, and when this modification is done, it requires significant capital. Regeneration on the other hand is economically expensive to modify, but the easiest otherwise.

This contextual information gathered from the physical layout of the cards is not immediately apparent due to the personal preferences of the interviewees. Any and all assumptions must be supported by a direct question directly asking for clarification during the specific structured section.

The choice behind the seven groups of soft adaptation measures comes from the groups created for the catalog during Block 2 of the research. The eighth card of the hard adaptation measures is meant to assist with comparison (interviewees are expected to be very familiar with it). This approach aims to address all the requirements mentioned previously in the following ways:

- Ordinal data sees commonplace usage in structured interviews and questionnaires (usually through the Likert scale). It is very easy to statistically analyze large sets originating from different sources, although certain mistakes must be avoided, and many statements cannot be directly proven.
- Additionally, the ordinal data is not affected by an interviewee's refusal or inability to answer, since it is completely relative, and has no anchoring to specific parameters.
- The physical aspect of moving the cards one by one is a novel touch to the interview, meant to stimulate discussion and help with the unstructured sections.

**Unstructured questions**

Unstructured questions do not require much specific preparation since they are meant to naturally arise throughout the unstructured sections of the interview, and the interviewee is meant to be the main driver of the conversation. This does not mean that there has been no consideration of them, but that the focus has remained on how to best stimulate the discussion in case it struggles to develop naturally. There are two main ways to stimulate interaction:

1. The interviewee themselves decides to share their thought process behind the ranking they just made when answering the prepared question. Since it does not have a noticeable impact on the direction of the discussion, it is optimal for the unstructured sections. This is stimulated throughout the entire process by encouraging them to think out loud and share any nuance they consider relevant to the topic. It can be externally assisted by the researcher through simple questions such as:
    - Do you mind explaining why measure X is in this position?
    - What makes you think this is best placed here?
2. The interviewee is shown examples of rankings done by other experts in previous interviews and asked about their thoughts or how their ranking compares. Additional remarks or details shared in previous interviews are also brought up to better engage the interviewee. This is the preferred option if the expert does not wish to discuss of their own volition, due to the nonrestrictive manner of the discussion. This effectively encourages the expert to defend their ranking if it differs from the ones made by other people or confirm previous statements if their ranking is similar. To minimize result pollution from social pressure effects, the interviewee is not allowed to vary their original rankings unless they have a strong justification or explain the change in detail. Some examples could be:
    - Previous rankings placed this measure last, yours has it first. How could that be?
    - Other experts shared that the elevated cost for these measures stems from their dependence on infrastructure. What do you think?
3. Pre-arranged follow-up open questions. These questions direct the discussion toward the next question but still allow for some nuance and discussion from the interviewee, who can choose to answer the question in any way they see fit. However, due to their more restrictive nature, reaching almost closed question levels, they are best avoided unless necessary. Specific examples of such follow-up questions are included in table [6.1].

Additionally, it is important to note that unstructured questions represent a significant chance to receive contextual data that can assist with the understanding of the answers provided to the structured questions. Personal bias is ever-present in any interview research, and these questions can help shed some light on it.

### 6.2.4. Lines of questioning

The main data-gathering goal from subsection [6.1.2] centered around the need to gather data on how soft adaptation measures perform in specific categories. This vagueness can be reduced by revisiting the sub-research questions that open the chapter. These questions mention costs and benefits, and measure interaction, which provides immediate lines of questioning to utilize.

Additionally, in subsection [6.2.3], it was explained that the questions asked during the structured sections of the interview concern the ranking of soft adaptation measures from worst to best on specific parameters or criteria, while the questions asked during the unstructured sections of the interview are intended to provide contextual information unique to each interviewee.

All of these aspects are used as the base to develop the interview lines of reasoning, which are covered together within Table [6.2].

| Sub-research question answered | Line of questioning | Explanation | Justification | Source |
|---|---|---|---|---|
| SQ3 | Economical cost | Economical cost concerns the capital investment required for the measure. | Economic cost is a core aspect of any project analysis. | (Stern 2007) (IFC 2010) |
| | Political cost | Political cost refers to the difficulty in getting policymakers to approve this measure. | Literature mentions the bias policy-makers show against soft measures. | (Dolšak and Prakash 2018) (Brooks, Anderson, et al. 2011) |
| | Social engagement | Social engagement refers to the end-user engagement needed to apply the measure. | Literature argues that soft adaptation involves active engagement of the end user. | (Swart and Raes 2007) (Boruff, Emrich, and Cutter 2005) |
| | Cost-effectiveness | Cost-efficiency refers to how many euros of protection is obtained per euro invested in the measure. | Cost-efficiency is better than pure efficiency since it accounts for economy of scale. | (IFC 2010) (Stern 2007) |
| | Flexibility & Reversibility | Flexibility refers to the amount of lock-in the measure displays, mainly environmental. | Literature describes flexibility as a central benefit of soft adaptation vs hard adaptation. | (Hallegatte 2009) (Noble et al. 2014) |
| SQ4 | Interaction | Interaction refers to the potential impact a measure has on other measures, whether that impact is positive or negative. | Literature consistently mentions the benefits of combining different adaptation measures in tandem. | (Noble et al. 2014) (Bailles, Garcin, and Bulteau 2020) |

**Table 6.1:** Table covering the six lines of questions covered in the interview process, with some brief explanations, justification and sources.

In addition to the information provided by Table [6.1], Table [6.2] provides the specific questions asked for the structured sections of the interviews, and some examples of questions that could be asked to stimulate discussion during the unstructured sections.

| Sub-research question answered | Line of questioning | Structured question | Unstructured question |
|---|---|---|---|
| SQ3 | Economical cost | Please rank the measures from most expensive to cheapest. | How are costs distributed time-wise? Are there maintenance considerations? |
| | Political cost | Please rank the measures from hardest to easiest to pass through a municipality. | How does political cost develop over time? How can the current government impact it? |
| | Social engagement | Please rank the measures from most to least required end-user engagement. | How does engagement develop over time? How could the end-user impact this? |
| | Cost-effectiveness | Please rank the measures from lowest to highest cost efficiency. | What about pure effectiveness? Economy of scale considerations? |
| | Flexibility & Reversibility | Please rank the measures from highest to lowest level of lock-in. | What do you think about political lock-in? |
| SQ4 | Interaction | Please rank the measures from least to most impact on other measures. | Could you group measures based on "buddy" groups that work well together? |

**Table 6.2:** Model questions for each line and section of the interview

### 6.2.5. Target audience

The last aspect of interview research concerns the selection of the interview targets themselves. This process is referred to as sampling, and there are a myriad of options when it comes to the reasoning behind the choices. For this research, only one type of sampling makes sense, purposive sampling (Stratton 2024). This approach, also referred to as "selective" sampling, is a non-probabilistic method where the targets of the interviews are selected directly by the researcher on account of their expertise or experience with the topic.

The following itemized list covers all the traits that make an interview target desirable for the interviews. To facilitate the sampling stage and increase potential targets, they do not need to have all the traits listed; just one of them is enough. Additional traits are however, extremely desirable, and such targets will be approached first. Table [6.3] shows the list of traits, a brief justification, and when relevant, the source from which the justification arises.

| Desireable trait | Justification | Source |
|---|---|---|
| Practical experience working with flooding or end-user. | Practical experience provides firsthand knowledge on flooding, what is needed, what works best, and what does not. | - |
| Practical experience working with disaster management. | Disaster management has significant overlap with soft adaptation measures, literature even makes some points on this. | (Dolšak and Prakash 2018) (Wen et al. 2023) |
| Experience with hard adaptation measures in flooding. | Having experience with hard measures provides insights into how it functions, its theoretical strengths, and weaknesses. | - |
| Experience with soft adaptation measures in flooding. | Similarly, experience with measures catalogued as soft provides insights to their design, inner workings, and benefits. | - |

**Table 6.3:** Desirable traits from experts.

On top of these traits, it is also highly desirable to sample targets encompassing every layer involved in the processes related to the field. Table [6.4] includes all the layers involved for the topics of flood protection and disaster management, with justifications and direct sources for each, when applicable.

| Involvement layer | Justification | Source |
|---|---|---|
| First responders (firefighters/police) | They have direct involvement with the consequences of soft adaptation measures. They are also end-users. | - |
| Private consultancy firms | In the Netherlands, there is a strong connection between the government implementing the measures and private consultancy firms offering assistance. | (NWP 2025) |
| Research institutes / academic institutions | Similar to consultants, research / academic institutions assist the government with adaptation needs. | (NWP 2025) |
| Regional water boards (Unique to NL) | A unique governmental institution from the Netherlands, the water boards, oversee the water management of their designated regions. This includes flooding. | (Algemene Zaken 2017) |
| Government (Municipal and National) | Municipalities have direct control over what adaptation is implemented within their municipal limits. | (Algemene Zaken 2017) (NWP 2025) |
| Coordinator for Terrorism & Security | In the event of a catastrophic event, the NCTV becomes involved to address immediate reactionary needs. | (Zaken 2016) |

**Table 6.4:** Layers of involvement for flooding adaptation in the urban environment.

This project created a total of 25 desirable targets, encompassing every category. The elevated number of potential targets accounts for expected erosion, since most targets are expected to decline/cancel during the interviewing stage. Overall, the list includes experts from every layer and with every trait, with the only category missing an expert being one from the National Coordinator for Counterterrorism & Security (NCTV in Dutch).

An additional expert, a first responder hailing from the Spanish region of Valencia, was included in the research, justified by their extensive first-hand practical experience with the catastrophic flooding events that happened in the Valencian Community last year (BBC 2024; Tanno et al. 2024). This case is of particular interest due to the existence in the area of robust flood-defense infrastructure, extensive information systems, and evacuation plans in the region, not too dissimilar from the Netherlands. The infrastructure and crisis planning, however, did not prevent the event from causing over 200 deaths and over 4.5 billion euros in material damages, setting records for one of the worst climate disasters in Spain's history.

### 6.2.6. Ethics

Ethics play a central role in any research, but this role becomes particularly poignant when involving human participants in the research, such as interviewed experts. Even when it is not immediately apparent, risks are present, and protecting the experts who decided to contribute to the research is of utmost priority.

Besides the mandatory review and approval of the project plan by the Human Research and Ethics Committee of the TU Delft, this project has taken extra measures to guarantee the anonymity and sense of control of its contributors. As such, the following additional measures have been taken.

- The specific layers and professional fields from which each expert originates have all been eliminated from the thesis, to reduce the chance of guesswork by elimination. Some generalized examples have been shared, even when they did not yield an expert due to scheduling incompatibility.
- Every single insight gathered from the interview stages has been filtered by the expert from which it originates, and their approval has been imperative before utilizing it further in the research in a completely anonymous manner.
- Experts were able to withdraw their contribution to the research at any point, up to a couple of weeks before the publication of the thesis in the TU Delft repository.

Interview targets were made aware of these extra layers of protection through the informed consent forms they were provided before joining the research. A blank form identical to the one sent to participants is visible in Appendix [C].

## 6.3. Data gathering results

The results themselves are split into three subsections. Subsection [6.3.1] concerns the logistical results when organizing the interviews. Subsection [6.3.2] covers the ordinal rankings themselves. Lastly, Subsection [6.3.3] covers the results from the unstructured discussion.

### 6.3.1. Answers & logistics

From the target audience subsection [6.2.5], there were a total of 25 tentative experts contacted. They were contacted directly through email, and the topic of the project was introduced. If they reacted with interest, they were then formally invited to contribute to the study in the form of an interview. The experts were given full choice concerning meeting times and space (either physical or online).

Figure [6.8] shows the number of targeted experts who reacted positively at each stage. It can be seen that there was significant erosion within each stage, usually from a cessation of communication on the targeted expert's part or sudden changes in availability. The final number of realized interviews dropped to 8, a successful hit rate of 32% compared to the original 25 contacts.

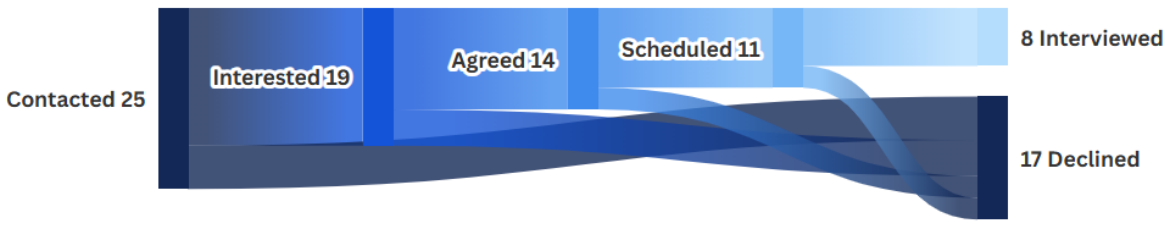



**Figure 6.8:** Sankey diagram showing expert responses to each step of the interview schedule.

Additionally, most interviews happened in a digital medium (Microsoft Teams specifically), with a minority happening in person. The average duration of interviews hovered around 1 hour, with the vast majority of them taking somewhere between 50 minutes and 1 hour and 15 minutes.

Table [6.5] provides an exact list of the interviews, with the layer of the expert, their work position, a brief justification for their inclusion, the format of the interview and their country of work.

| Interview | Layer | Position | Justification | Format | Country |
|---|---|---|---|---|---|
| 1 | Municipality | Urban strategic manager. | Directly responsible for the adaptation portfolio of the urban space. Experience with the municipal politics and adaptation implementation. | Online | NL |
| 2 | Private consultant | Consultant in technical systems for flood risk management. | Focuses on the IT side of a flooding risk management. Extensive experience with information systems and warning systems, among others. | Online | NL |
| 3 | Research institution | Applied researcher. | Has background in water management and projects in the socio-engineering barrier. | Online | NL |
| 4 | Research institution | Applied researcher. | Has background in marketing and focuses much of their research in improving and understanding social engagement. | Online | NL |
| 5 | Water board | Policy advisor for crisis management. | Direct experience with crisis management, closely tied to flooding and water management. | Online | NL |
| 6 | Water board | City climate adaptation program coordinator | Extensive experience with adaptation options in every aspect, both hard and soft. Some extra background around national politics in the Netherlands. | Online | NL |
| 7 | First responder | Firefighter coordinator in a city inthe Valencian Community | Firsthand experience during the catastrophic flooding events in the Valencian Community during late 2024. As a first-responder coordinator, they had access to additional information and can share practical insights. | Online | ES |
| 8 | Private consultant | Consultant in flood risk management + PHD in evacuation | Focused entirely on flooding adaptation, with a hybrid focus on all measures. Extensive research in evacuation specifically during academic phase. | In person | NL |

**Table 6.5:** Final list of completed interviews. With position, layer, justification, format and country of origin.

An additional consideration concerns the union of interviews 3 and 4 into one joint session. Experts requested this simultaneous interview in order to be able to debate and discuss their results with one another between interview sections. Therefore, they each provided a set of rankings but due to the joint discussion, only one insight log for the two interviews, denoted as "Interview 3-4" in subsection [6.3.3], is recorded.

## 6.3.2. Structured section results

This subsection provides the ordinal rankings for each line of questioning experts gave during the structured sections of each interview. Every line is covered individually, with its own table of results and some contextual information from the interviews themselves. As a general rule, a large number ranking indicates poor performance in the category, while a small number represents a strong performance. A color legend has been introduced to assist with clarity; it does not carry any additional meaning besides providing an immediate visual aid. This legend uses the red-green colour spectrum, with intense reds denoting lower rankings and intense greens higher rankings.

### Economic costs

Experts were asked to rank measures from the one requiring the most capital investment (ranked with 8) to the one requiring the least (ranked with 1) total investment overall. The ranking ignores how the cost distribution is over time; it is based on total cost. Table [6.6] provides the rankings for every interview.

| ECONOMIC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 8 | 5 | 7 | 6 | 1 | 2 | 3 | 4 |
| INTERVIEW 2 | 8 | 5 | 7 | 2 | 3,5 | 6 | 1 | 3,5 |
| INTERVIEW 3 | 7 | 1 | 2 | 5 | 4 | 6 | 3 | 8 |
| INTERVIEW 4 | 8 | 4 | 2 | 6 | 3 | 7 | 1 | 5 |
| INTERVIEW 5 | 7 | 5 | 2 | 6 | 1 | 3 | 4 | 8 |
| INTERVIEW 6 | 7 | 6 | 3 | 2 | 1 | 4 | 5 | 8 |
| INTERVIEW 7 | 7 | 5 | 6 | 4 | 3 | 1 | 2 | 8 |
| INTERVIEW 8 | 8 | 5 | 2 | 6 | 1 | 7 | 4 | 3 |

**Table 6.6:** Ordinal rankings for economic cost from the interview stage.

The vast majority of interviewees were quite confident, and no measures were excluded from this criterion during any interview. Most experts started by ranking hard measures, education, evacuation, and warning systems first, after which they proceeded to place the others through comparison. Additionally, there were many immediately apparent trends in the rankings, most noticeable with hard measures and zone management, which usually ranked in the expensive half, or with administrative and educational measures, which were consistently ranked in the cheap half.

### Political costs

For political costs, experts were invited to imagine themselves in front of a legislative body, namely a municipal council (Gemeenteraad in Dutch). They were then asked to rank measures from hardest (ranked with 8) to easiest (ranked with 1) to pass through the legislative body. The reasoning for the difficulty was not considered, only the difficulty itself. Table [6.7] shows the rankings.

| POLITICAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 6 | 4 | 8 | 5 | 2 | 3 | 1 | 7 |
| INTERVIEW 2 | 6 | 8 | 4 | 5 | | 7 | 3 | |
| INTERVIEW 3 | 3 | 7 | 2 | 4 | 5 | 1 | 6 | 8 |
| INTERVIEW 4 | 2 | 5 | 6 | 4 | 8 | 1 | 3 | 7 |
| INTERVIEW 5 | 7 | 1 | 3 | 5 | 2 | 6 | 4 | 8 |
| INTERVIEW 6 | 1 | 7 | 4 | 3 | 5 | 2 | 6 | 8 |
| INTERVIEW 7 | 7 | 4 | 2 | 6 | 5 | 3 | 1 | 8 |
| INTERVIEW 8 | 3 | 4 | 5 | | | 2 | 1 | |

**Table 6.7:** Ordinal rankings for political cost from the interview stage.

Most experts showed unfamiliarity with the political sphere, especially with regard to specific measures. As such, some experts excluded measures from their rankings voluntarily to avoid the potential data pollution from random guesses. Immediate trends within the political costs include regeneration being a tough sell to legislative bodies, and warning systems being easy to get through to policymakers.

### Social engagement

As explained in subsection [6.1], social engagement refers to the required engagement from the end-user to ensure proper utilization of the measure. Experts were asked to rank measures from the one requiring the most end-user involvement or active participation (ranked with 8) to the one requiring the least, if any (ranked with 1). The results are once more placed in Table [6.8].

| SOCIAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 2 | 4 | 5 | 7 | 3 | 1 | 8 | 6 |
| INTERVIEW 2 | 6 | 5 | 4 | 8 | 2 | 1 | 7 | 3 |
| INTERVIEW 3 | 1 | 7 | 4 | 2 | 6 | 3 | 8 | 5 |
| INTERVIEW 4 | 2 | 4 | 5 | 6 | 1 | 7 | 8 | 3 |
| INTERVIEW 5 | 7 | 2 | 5 | 3 | 8 | 1 | 4 | 6 |
| INTERVIEW 6 | 4 | 7 | 5 | 2 | 1 | 3 | 6 | 8 |
| INTERVIEW 7 | 1 | 3 | 4 | 7 | 2 | 5 | 8 | 6 |
| INTERVIEW 8 | | | | | | | 8 | |

**Table 6.8:** Ordinal rankings for social engagement from the interview stage.

Experts were confident in their rankings, and no measures were excluded from the rankings due to uncertainty. The clearest trend is educational measures carrying elevated social costs, with one expert going as far as only ranking education at the absolute bottom and grouping the other seven measures together outside of the scale, indicating the extreme difference between educational measures and the rest. Additionally, hard measures, administrative measures, and warning systems were often ranked at low social costs.

### Cost-efficiency

Cost-efficiency was described as the rate of return each measure had based on its initial investment. That is to say, for each euro invested, how many euros' worth of damages were avoided? Measures were therefore ordered from least cost-efficient (ranked with 8) to most cost-efficient (ranked with 1). Table [6.9] provides the full rankings.

| COST-EFFECTIVENESS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 3 | 5 | 2 | 7 | 6 | 4 | 1 | 8 |
| INTERVIEW 2 | 5 | 6 | 7 | 1 | 3 | 4 | 2 | 8 |
| INTERVIEW 3 | 6 | 2 | 7 | 3 | 1 | 5 | 4 | 8 |
| INTERVIEW 4 | 5 | 6 | 8 | 1 | 3 | 4 | 2 | 7 |
| INTERVIEW 5 | 8 | 3 | 2 | 4 | 5 | 1 | 6 | 7 |
| INTERVIEW 6 | 3 | 6 | 4 | 2 | 7 | 1 | 5 | 8 |
| INTERVIEW 7 | 1 | 4 | 8 | 6 | 7 | 3 | 2 | 5 |
| INTERVIEW 8 | 1 | 4 | 6 | 2 | 6 | 2 | 5 | 6 |

**Table 6.9:** Ordinal rankings for cost-effectiveness from the interview stage.

Cost efficiency rankings were subject to significantly more doubt and self-discussion among the experts, with no clear apparent trends. A notable exception is regeneration measures, which ranked extremely poorly across all expert interviews. Evacuation and warning systems also show some trends towards the upper half of the ranking.

### Flexibility & reversibility

For flexibility and reversibility, experts were asked to rank measures from those subject to the most lock-in (ranked with an 8) to the ones showing the least (ranked with a 1). This lock-in was framed uniquely around the potential for climate change predictions to vary, actively disregarding human lock-in due to political ideologies or infrastructure systems. The final results for this line of questioning are shown in Table [6.10].

| FLEXIBILITY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 7 | 5 | 6 | 4 | 3 | 2 | 8 | 1 |
| INTERVIEW 2 | 8 | 7 | 6 | 2 | 4 | 1 | 3 | 5 |
| INTERVIEW 3 | 8 | 7 | 1 | 2 | 4 | 3 | 6 | 5 |
| INTERVIEW 4 | 8 | 7 | 2 | 5 | 3 | 4 | 1 | 6 |
| INTERVIEW 5 | 8 | 4 | 1 | 7 | 5 | 3 | 2 | 6 |
| INTERVIEW 6 | 8 | 4 | 3 | 7 | 5 | 2 | 1 | 6 |
| INTERVIEW 7 | 3 | 5 | 1 | 7 | 4 | 6 | 2 | 8 |
| INTERVIEW 8 | 6 | 8 | 1 | 1 | 7 | 1 | 1 | 1 |

**Table 6.10:** Ordinal rankings for flexibility from the interview stage.

Flexibility shows the most general consensus yet, with most measures having a consistent position when looking at all the rankings together. Hard measures are a clear low ranker in flexibility, together with zone management. Warning systems and educational measures, on the other hand, show strong performance in their elevated rank. Regeneration and Evacuation show uniqueness in their apparent trend, at the bottom and top percentiles, respectively, which is shattered by two significant outliers.

**Interaction**
Interaction is the last line of questioning in the interviews. Experts were asked to rank measures on their potential impact on other measures. The ranking goes from measures that have a low impact (ranked with 8) to measures that have a high impact (ranked with 1) on others. In addition to this line of questioning, experts were asked to indicate where this interaction, if any, was most significant. Table [6.11] shows the final results for this line of questioning.

| INTERACTION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| INTERVIEW 1 | 5 | 3 | 4 | 7 | 6 | 1 | 2 | 8 |
| INTERVIEW 2 | 4 | 5 | 8 | 1 | 6 | 3 | 2 | 7 |
| INTERVIEW 3 | 5 | 2 | 7 | 8 | 1 | 6 | 3 | 4 |
| INTERVIEW 4 | 5 | 1 | 8 | 7 | 6 | 4 | 2 | 3 |
| INTERVIEW 5 | A | C | B | C | B | C | B | A |
| INTERVIEW 6 | A | A | B | B | B | B | B | - |
| INTERVIEW 7 | C | A | C | B | A | B | B | C |
| INTERVIEW 8 | A | A | B | A | B | A | B | B |

**Table 6.11:** Ordinal rankings for interaction from the interview stage.

There is an immediate, unique disruption in the table. The second half of the experts were unable to provide an ordinal ranking for this criterion. The reasoning given was that interaction varied strongly between measures, and while some measures barely interacted with others, they might interact strongly with a hypothetical third measure. Effectively, it was argued that context is relevant and interaction can not be compared across the entire field with a comparative scale.

These experts decided instead to group measures based on how they believed interaction between them is most significant, effectively creating "groups of friends" among measures that have strong interaction between themselves. In table [6.11], the letters indicate such groups of friends. Measures that have the same letter belong to the same "group of friends" and present, according to the expert, strong interaction between them. The letters are independent for each interview, so the groups marked with A from interviews 5 and 6 are independent of each other. Specific examples include the grouping during interview 5 of hard measures and regeneration measures into a pair with strong interaction, denoted by the letter A, as it was the first group discussed by the expert. During interview 7, a similar grouping happened, this time including evaluation together with the previous two; this grouping is marked with the letter C since it was the third and last grouping the expert discussed.

### 6.3.3. Open question results
The results from the unstructured discussion sections of the interviews are compiled in the form of explicitly quoted sentences or summaries that distill a topic of discussion into a key insight. Due to their extensiveness repetitive format, this subsection only covers the answers to the open questions derived from table [6.2]. A detailed analysis of an insight log (from interview 1) is placed in Appendix [B]. Additionally, the reader may find all of the interview insight logs in Appendix [A], in their unfiltered form.

These insights are split into the six lines of questioning, taken from section [6.2.4]. A seventh and last category in the log comprises any statements deemed general and outside of the scope of the previous six.

Most discussions began spontaneously on the side of the interviewee. The utilization of the open questions from table [6.2] allowed for this discussion to be channeled towards relevant aspects. This resulted in discussions being varied between interviews, but covering similar topics. The insights written in the logs come in three main shapes:

1. Justification for the ranking: The interviewee further explains why they believe a measure ranks in one way or another. It is the most common type of statement.
2. Interesting topic: The interviewee discusses a topic they consider interesting and relevant to the adaptation measures discussed.
3. Answer to an open question: The interviewee directly answers a question drawn from table [6.2].

As previously mentioned, a detailed breakdown of an insight log sheet from a full interview (interview 1) is included in Appendix [B]. Each statement in the log is grouped into one of the three previously mentioned categories.

Table [6.12] shows the answers to the open questions presented in table [6.2]. The answers are drawn from all the insight logs gathered, and the referencing links the answer back to the main interview(s) from which it was extracted. They are covered individually in the subsequent pages.

| Line of questioning | Open question | Answer | Sourced from |
|---|---|---|---|
| Economic cost | How are costs distributed time-wise? | Generally speaking, hard measures frontload costs, soft measures backload them. Most measures pack costs into batches. | 1,3-4,6,7 |
| | Are there maintenance considerations? | Yes, for hard measures the maintenance is physical, for soft measures it is technological or human, since they involve monitoring, updating and modifying. | 1,2,3-4 |
| Political cost | How does political cost develop over time? | Current world events appear to have massive impact on the development of political costs. If flooding is a currently poignant topic, it will reduce the political cost of all measures for some time. | 1,7,8 |
| | How can the current government impact it? | The political alignment of the government can have an impact on which measures are deployed and to what depth. Their level (national, regional) also has an impact on what they consider relevant. | 3-4,5 |
| Social engagement | How does engagement develop over time? | Similar to political cost, current events could have a large impact on how much social engagement is needed. The engagement quality is also relevant. | 1,5,7,8 |
| | How could the end-user impact this? | The end user can impact the engagement needs based on their perception of the measure's utility, culture, and socio-economic capital. | 1 |
| Cost-effectiveness | What about pure effectiveness? | Hard measures are unbeatable in pure effectiveness, since they are the only ones capable of directly preventing flooding. | 7,8 |
| | Economy of scale considerations? | Some measures quickly balloon in costs when the scope or depth of the measure increases. | 2 |
| Flexibility & reversibility | What do you think about political lock-in? | While it can be a relevant issue during day-to-day operation and implementation. During crisis events there is little political discussion (in NL). | 1 |
| Interaction | Could you group measures based on "buddy" groups that work well together? | (Check figure [7.1] for the results to this question) | - |

**Table 6.12:** Answers to open questions posed in table [6.2] with sourcing from the interviews that provided the main answer.

**How are costs distributed time-wise?**
There was a consensus among the experts on costs being packed into big batches, as opposed to constant cash flow. The majority of experts also agreed on hard measures necessitating a larger percentage of the total investment upfront, to cover the construction phase. Experts also agreed on soft measures, back-loading costs, owing to the reliance on policy and limited infrastructure, which requires a lower initial investment. How this back-loading of costs happened was less consistent. Some experts argued for recurring monitoring and social maintenance costs (e.g., personnel costs for educational measures). Other experts argued for a large cost after the measure has been engaged instead (e.g., Insurance payouts after the crisis event).

**Are there maintenance considerations?**
Interviews aligned on maintenance costs, for both soft and hard measures. Hard measures carry their maintenance in a physical way, requiring investment to repair and maintain the infrastructure assets that comprise the hard adaptation measure (e.g., fixing dykes). For soft adaptation measures, the maintenance requirements come in the form of technological, monitoring, or human costs. Experts did not show consensus, however, on the scale of the maintenance expenses. Some experts argued that hard adaptation measures carry higher maintenance costs than soft adaptation measures, and that they are often underestimated. Other experts argued instead that maintenance for soft adaptation measures appeared lower due to the costs being spread around multiple assets, instead of centered around a large item.

**How does political cost develop over time?**
Interviews are aligned with the fact that current world events have a noticeable impact on the political cost of a measure. The form and size of this impact were less consistent. Some experts discussed how

the positive performance of adaptation measures during flooding events elsewhere could lower the political cost. Similarly, negative performance of measures could increase the political cost, since the measure proved ineffective at increasing flooding resilience. This impact was argued by some experts to not be that simple. Aspects such as culture, government structure, and climate could also have an impact. To provide a hypothetical example, the positive performance of a measure in a flooding event in Bangladesh would not guarantee that the measure becomes easier to pass in the French political sphere, since they are not analogous situations. Climate, population density, existing infrastructure, urbanization, and even government culture are remarkably different. According to the experts, these are relevant factors when evaluating a measure politically.

**How can the current government impact it?**
Experts argued that there are two general aspects to consider: the political alignment and the level of government. The political alignment relates to the disposition shown by the current government towards authority. Some quadrants of the political spectrum favor centralized responsibility, favoring extensive measure deployment and increased social engagement. Other quadrants of the political spectrum favor personal responsibility instead, opting less for direct intervention and prioritizing personal freedom. The political alignment was, however, mentioned not to be extremely important nowadays. Interviews discussed that the more relevant aspect is the level of government. The level of government directly links with the portfolio of responsibility, and some levels of government will prioritize some measures over others, if they consider them to be part of their sphere of responsibility (e.g., Educational measures could be prioritized by the national government, while zone management could be prioritized by municipal governments).

**How does engagement develop over time?**
Experts were divided into two main points. Some experts argued that, similarly to political cost, current events could have a significant impact on the engagement required by most soft measures. The perceived necessity of the measure by the end-user was argued to be the underlying aspect driving the impacts. If current world events made the end-user believe the measure was necessary or/positive, the engagement would become easier and higher quality. The opposite case could also happen.

Not all experts agreed with this notion, and some believed that the quality of the engagement had a lot more impact than current world events. Good engagement in the present would lead to easier engagement in the future. The opposite could also happen.

**How could the end-user impact this?**
Very few experts were able/willing to discuss this. The few that shared discussed the relevance of socio-cultural and socio-economic aspects. Culture was argued to play a role in engagement since each culture values different aspects of society and reacts to authority in a different way (e.g., some cultures prioritize close family over the general good). Socio-economic aspects were also argued to impact engagement, mainly in the form of income brackets (e.g., lower-income end-users might be reluctant to abandon their possessions in an evacuation call, due to fear of them being stolen). Overall, the noticeable lack of answers displays the sensitive nature of the topic.

**What about pure effectiveness?**
Experts all agreed that hard adaptation measures are generally unbeatable in pure effectiveness when compared to soft adaptation measures. This increased effectiveness comes from their ability to physically prevent flooding events altogether (e.g. dykes should completely protect against floods below their maximum design capability). Some soft adaptation measures, such as complete relocation and migration, would theoretically provide absolute effectiveness, but every expert considered them completely unrealistic and extremely cost-inefficient, with the vast majority not even acknowledging them as actual options. Soft adaptation measures with high effectiveness include zone management (owing to their ability to act as a small migration/relocation) and those centered on minimizing damage to human assets. Some experts argued that most soft adaptation measures cannot be well analyzed since they increase the effectiveness of other measures, and are not that effective in a vacuum. For example, administrative measures will not do anything against a flood on their own, but will increase the effectiveness of other measures deployed.

**Economy of scale considerations?**
Most experts did not discuss the topic in depth. One expert discussed that soft adaptation measures increase their costs exponentially as they grow in scope or size (e.g., a soft adaptation measure 2x the size would cost 4x more). Other experts mirrored this thought and expanded by adding that soft adaptation measures are harder to effectively apply as they increase in complexity. This is different from hard adaptation measures, which were argued to scale less exponentially as the size/scope of the project increased (a hard adaptation measure 2x the size would cost 2.5-3x more).

**What do you think about political lock-in?**
Most experts could not give a detailed answer to this question, mainly due to their unfamiliarity with the inner workings of the political sphere. Those who did answer discussed how lock-in depends significantly on the stage discussed. Political lock-in refers to how feasible it is to get policymakers to agree on changing the measure once the measure has been deployed. During the planning, implementation, and general operation stages, it is a relevant issue, and most measures face significant lock-in due to the lack of interest from policymakers on constant revisits of the measure. During crisis events, experts argued that political lock-in is disregarded. The authority responsible for the measure is afforded more liberty with regards to changing it and will instead have to justify their decisions after the crisis event.

**Could you group measures based on "buddy groups" that work well together?**
All experts answered this question with interest, and it sparked some of the longest discussions in the entire interview stages. Despite the high subjectivity attached to the answers, some immediate patterns appeared in the answers. Experts generally brought up educational and administrative measures the most, and argued that they had a positive interaction with pretty much every other adaptation measure. Regenerative measures, on the other hand, were brought up less often and had more restrained avenues of interaction. Additionally, every soft adaptation measure was argued by at least one expert to have direct interaction with hard adaptation measures. The complete results are displayed in Figure [7.1], with a detailed analysis following right after.

# 7

# Soft adaptation measure evaluation

The previous chapter represents the first half of the third and final research block; it focuses on the data gathering. This chapter represents the second half and focuses on the interpretation of the data gathered, with the overall goal of answering the two sub-research questions that drive the research block. These questions are:

3. *What are the advantages and disadvantages of each of these measures?*
4. *How do soft measures interact with each other? And with hard measures?*

Internally, the chapter is split into four sections. Section [7.1] covers the challenges present within the data analysis and the goals subsequently derived to tackle them. Section [7.2] covers the methodology employed for the data analysis. The final results of the qualitative analysis are covered in section [7.3], where the sub-research questions themselves are answered.

## 7.1. Designing an effective analysis approach

This section discusses the challenges and the goals that define the approach to take when considering the data analysis part of the research block. The first subsection concerns the challenges that need to be addressed by the data analysis, while the second outlines the objectives that the data analysis must meet to effectively provide an answer to the research questions.

### 7.1.1. Current challenges

Due to this chapter representing the second half of the research block, the challenges include both some gathered from the literature review and some that arise directly from decisions taken in the data-gathering stage. They include:

1. Current analysis tools, which focus purely on economic-based quantitative data, are not well suited to describe soft adaptation measures, as plenty of their benefits are more abstract and they present strong interaction between themselves.
2. Some quantitative datasets are incomplete due to experts declining to answer in the intended way.
3. Ordinal data carries statistical peculiarities that have to be addressed, and certain statements cannot be made with certainty.
4. Even when the data is quantitative, it remains abstract and presents uncertainty risk.

The first challenge is of significant relevance since it acts as a hard barrier that is not really avoidable and limits the options available for the overall analysis. It is the main challenge of the Third Block B. The other three challenges have a direct relation to the underlying statistics attached to preparing and streamlining the data gathered in the previous chapter. The main concerns of the data analysis will be dealing with the potential of uncertainty, the lack of complete datasets, and the peculiarities that come attached to the utilization of ordinal data.

### 7.1.2. Data analysis goals

The overarching goals of this chapter are to provide answers to the sub-research questions that drive the third research block while addressing the challenges detected in the previous section. The objectives of the data analysis are the following:

1. Incorporates all the data relevant to the research questions, which will allow for the abstract categories to be included alongside the more traditional ones
2. Ensure that incomplete datasets do not impact the reliability of the results. A measure ranked last in an incomplete dataset (6th or 5th) has to be weighted equally to one ranked last in a full dataset (8th).
3. Expert bias and the subsequent uncertainty need to be accounted for in the data analysis.
4. Account for the peculiarities that come with the utilization of ordinal data.

Once again, the first goal provides the central objective of the chapter, as it guides the methodology design process of the whole analysis, aligning it towards providing results useful and can answer the research questions. The other three goals refer once more to the underlying preparation of the data so that it can be used in the analysis itself.

From the list of challenges and objectives, it can be seen that the final analysis approach must be able to incorporate multiple criteria, some of them abstract, and not fall into the hyper-fixation surrounding economic factors that permeates the current adaptation policymaking field. Additionally, due to the contextual nature of soft adaptation measures, it should remain general and leave room for discussion.

## 7.2. Methodology

This section is internally subdivided into three subsections, each covering different topics. Subsection [7.2.1] covers the Multiple Criteria Decision Analysis (MCDA), from its justification for utilization to its application within the thesis. Section [**??**] concerns the brief statistical descriptors used to assist with the qualitative analysis. The topic of interaction and the peculiarities that arise from the broken dataset are covered in subsection [7.2.2].

### 7.2.1. Multiple criteria decision analysis

Multiple Criteria Decision Analysis (MCDA), also referred to as Multiple Attribute Decision Making (MADM), is a sub-discipline of Operations Research, a branch of Applied Mathematics centered on the creation of decision-making frameworks for use in management (Holstein 2025).

According to Zhang and Balakrishnan (2021), MCDA is a decision support tool widely used by government agencies for evaluating, assessing, and prioritizing project alternatives in circumstances where conflicting and competing objectives are to be achieved. MCDA techniques offer a systematic approach for decomposing a complex selection problem into a group of smaller and simpler problems (Z. Zhang and Balakrishnan 2021). The simplification eases the identification of the best alternative within a set of options (Z. Zhang and Balakrishnan 2021).

An MCDA is comprised of two main aspects that define it:

1. A set of options to evaluate.
2. A set of criteria to evaluate the options with.

To solve an MCDA problem, there are three common steps (L. Zhang 2014):

1. Assign weights to the criteria, also denoted as attributes in some research.
2. Normalize the attribute or criteria values for each alternative option.
3. Aggregate the normalized criteria values into an index, ranking the alternatives from best to worst.

The MCDA can be used either as a decision-maker itself or as a tool meant to assist a hypothetical stakeholder with the decision-making.

**Within this research**
Multiple Criteria Decision Analysis aligns with the objectives of the research block, due to its flexible nature and customization options, which make it possible to tailor to the needs and objectives of the third block of research. Some modifications have been applied to ensure better alignment with the sub-research questions central to the research block, and they will be covered further on.

To start, the formal definition of the MCDA for this research follows below:

1. The set of options to evaluate is comprised of the seven soft adaptation measure categories derived in the Second Block of the research, with an eighth option to add in the form of the hard adaptation measure. There is plenty of available information on them, thanks to the data gathered from experts during the interviews in the first half of the Third Block of research.
2. The set of criteria upon which to evaluate the options. The selection in this part is the first five lines (Interaction is excluded) of questioning derived from the data gathering part of the Third Block of research (Third Block A). Every adaptation measure alternative of the MCDA has been evaluated on these criteria, which facilitates the scoring of the options.

The next point of relevance concerns the methodology for the three commonly employed steps to solve MCDA. Similarly to the formal definition steps, they are covered individually:

1. Assign weights to the criteria. For this research, they are assumed to be all equal, since any justification for weighting them differently would have no academic rigor and be based on pure personal preference, which provides no utility when considering the sub-research questions.
2. Normalize the criteria values for every option. This is done by assigning values for the sets of data gathered in the research through a measure of central tendency. This numerical result acts as the preliminary score in the category for each measure group. This preliminary score is then further evaluated through a qualitative analysis. The analysis utilizes one of the measures as an anchor and comparatively evaluates the rest through the usage of the insight logs from the interviews to assign a final trinary grade (better, worse, or blank). The measure group to use as an anchor is chosen to be the hard measures group, due to their general familiarity and direct relation with the research questions.
3. Aggregate the results into an index and rank the measures. Similarly to the criterion weighting, this is not necessary for the research as it provides no value to the research question.

Steps one and three of the solving process are not considered relevant, so it can be immediately noted that "solving" the MCDA itself is not of particular interest to the research, and this is due to two main facts:

- The sub-research question does not concern which soft adaptation measure is best, and even if it did, the MCDA would introduce so much personal bias that the answer would provide little real value.
- The sub-research question is best answered by using both the overview from the MCDA and the qualitative insight logs from the interviews. Solving the MCDA reduces the available information from an overview to an abstract ranking.

Therefore, it can be inferred that the main desirable aspect of the MCDA is the output of its unweighted scoring matrix, which provides a visual overview of all the measures and their scores in each criterion.

As explained in step two of the MCDA solving, a preliminary matrix is created from statistical parameters. This matrix is then validated and expanded on through the qualitative analysis performed with the insight logs. The preliminary matrix is not authoritative in the final results, and is limited to a starting point for the rest of the analysis. The methodology and results of this preliminary matrix are covered in Appendix [D].

### 7.2.2. Interaction analysis

The analysis of interaction was complicated by the decision from some experts not to answer the structured question as originally planned, opting instead to group the measures into "groups of friends", where each measure in the group displayed strong interaction with each other. This means that the original approach that included interaction in the MCDA was not really feasible, as the ranking dataset is split and would require significant interpretation from the researcher to restore.

Due to this difficulty, interaction is not included in the preliminary MCDA, as the statistics would not be consistently applied, and it would be ineffective to use them. A direct qualitative analysis, with no preliminary ranking, is therefore the selected methodology for the criterion of interaction. The grouping of measures into groups that share strong interaction is attractive due to its ability to instantly show which measures have the most interaction with each other, but there is a similar problem to the ranking dataset, since only the latter half of the experts answered in this way. To solve this issue, a qualitative analysis was done on the insight logs. The interaction groupings for the first half of the interviews were extracted by searching for any explicit mentions of interaction between pairs of measures and recording any such instances.

## 7.3. Qualitative analysis results

This section provides the analysis and results of the qualitative analysis performed on the data. The inputs include the insight logs from appendix [A] and the preliminary MCDA matrix from appendix [D].

The section is divided into three subsections. Subsection [7.3.1] displays the analysis for each of the five lines of questioning. Section [7.3.2] covers the completed and final MCDA unweighted matrix, with the addition of the positives and negatives of each measure, aimed at answering SR3. Lastly, section [7.3.3] closes the chapter by covering measure interaction, aimed at answering SR4.

### 7.3.1. Lines of questioning

The following subsection provides the analysis performed on the eight adaptation measure groups. Each line of questioning is covered individually, for reading convenience.

#### Economic cost

Soft adaptation measures are generally agreed to be cheaper than hard adaptation measures, especially in the context of flooding resilience. Hard adaptation measures were ranked consistently low, and interview discussion insights also show this.

*Measures that require supplementary infrastructure tend to cost more. By extension, hard measures could be considered the most expensive.* (From Interview 3-4)

*Hard measures are quite expensive, especially in the short term. In the long term, it might be cheaper, but in general, it is pricy. Maintenance is significant and expensive; Shelf life is also relevant.* (From Interview 2)

Hard adaptation performs worse than soft adaptation due to the associated costs of the supporting infrastructure, which carries an elevated capital investment. Soft adaptation, on the other hand, relies mainly on policy, with usually little or no supplementary infrastructure, which makes it cheaper in general.

*Policy is cheap, with limited effectiveness if you just keep it as just words* (From Interview 8)

*The Top five measures [in the ranking] are purely organizational, so they do not incur significant consistent costs.* (From Interview 7)

*Some measures are not expensive themselves but come attached to supplementary costs.* (From Interviews 3-4)

This relationship between cost and supporting infrastructure should, in theory, be reflected in warning systems being ranked poorly, as they carry significant supplementary infrastructure requirements.

This hypothesis, however, does not materialize in the results, and warning systems sit right in the middle of the rankings, together with zone management. This can be explained by some experts internally separating the information-sharing aspect of warning systems from the supporting infrastructure.

*Administrative, evaluation, and evacuation policies, together with warning systems, are cheaper due to their tendency to be one-off or heavily based on planning, which is usually cheaper.* (From Interview 6)

*Warning systems are more expensive since they need extra power.* (From Interview 8)

*Warning systems can be quite cheap depending on the scale (100k [thousand] for example), but as you increase the scope, they get more expensive, fast. Overall, they are still cheaper than the average measure.* (From Interview 2)

The middle point of warning systems in economic cost reflects the discrepancy in what exactly is needed for the warning system in the minds of experts. The warning system itself is cheap if data gathering infrastructure already exists, but if not, then warning systems become more expensive, but less so than hard measures overall.

Evacuation follows a similar line of reasoning to warning systems, where the evacuation plans themselves are quite cheap, but the actual deployment of effective evacuation carries more noticeable costs due to supplementary infrastructure required when evacuating, especially when doing horizontal evacuation.

Additionally, some soft adaptation measures that do not carry any apparent additional infrastructure perform poorly in the rankings, such as regeneration and zone management. This poor performance in the economic cost ranking can be explained by considering statements from the insight logs.

*It is more expensive to regenerate than to build infrastructure in advance* (From Interview 7)

Regeneration is the second-to-last performer in economic cost due to its timing, which requires deployment after damage has already been done. As such, although the creation of insurance schemes is very cheap in theory, when they must be paid out, the cost of the measure balloons exponentially, arguably more than if preparation had been taken to reduce the flood damage instead.

Zone management lands in the center of the ranking due to the effective "offloading" of costs to the end user. Building regulations or urban planning policies are generally cheap, but there is a significant economic cost that has to be taken up by the end-user, subject to the zone management policies. A statement from interviews 3-4 summarizes this soft measure quite well.

*Zone management is a one-time administrative investment, while a lot of the ongoing costs are offloaded to the end user.* (From Interviews 3-4)

The best three performers encompass soft adaptation measures strongly encased in policy, in the form of educational, evaluation, and administrative. But there is an important distinction to remark, and that is the concept of measure scope.

*Educational and zone management are in the middle of the pack due to their ongoing maintenance requirements, and they can become expensive if their scope or complexity rises.* (From Interview 6)

*Educational campaigns are typically cheap and cost-effective. On a low level (low penetration or size), they can be implemented quickly and cheaply.* (From Interview 2)

These previous two statements illustrate the concept quite well. Measures will get significantly pricier as their depth and complexity are increased to encompass more aspects.

Overall, soft adaptation measures carry significantly lower economic investments than hard adaptation measures due to their focus on policy instead of physical infrastructure, but this difference can quickly close if the scope of the measures increases, either by encompassing more aspects or by

becoming more complex. Additionally, there is the aspect of cost offloading to the end-user, something that soft adaptation measures are much more likely to do.

**Political cost**

Political cost is not so immediately obvious, with some soft measures struggling less to get past legislation bodies than hard adaptation measures, and others struggling more. There appear to be multiple reasons for this.

*Economical [sic] cost is part of the political cost. Expensive things are harder to pass, regardless of their efficiency.* (From Interview 2)

*Economic and political costs go together. Low-hanging fruit are easy to pass since they don't cost much money.* (From Interview 5)

These statements discuss the immediate assumption that economic cost and political difficulty come packed together tightly. Regeneration, for example, is consistently ranked in political cost due to the fact that policymakers consider it a significant investment and will be reticent to invest in it. Naturally, it is not as simple as a direct relationship; otherwise, Hard adaptation measures would be ranked last. Which raises the topic of "regret".

*In general, policies are more likely to pass if they have a low impact on the community, such as evaluation or educational campaigns (no regret options).* (From Interview 2)

*Administrative measures can be difficult due to the mentality of hindsight (whiff, get the axe, don't swing at the right time, get the axe too) and don't waste if not needed* (From Interviews 3-4)

From these insights, it appears that policymakers gravitate away from adaptation measures that do not have clear, immediately recognizable benefits and that could be perceived as being a waste of public funds, such as administrative measures, or subject the end-users to unnecessary red tape, in the form of zone management measures. This aligns with research covered in the literature review and helps explain why, even though hard adaptation measures are deemed to be significantly more expensive, they don't struggle too much when passing through legislative bodies, as their results are easily quantifiable and they have a "proven record". Expert insights also support this assertion.

*Hard measures are not hard to sell due to their clear functioning.* (Interview 3-4)

*Hard measures are easy to pass since most regulatory bodies understand they are necessary to defend urban space.* (From Interview 6)

*Hard measures are relatively easy to pass since they are proven to work.* (From Interview 8)

The top performers in political cost appear to receive their spot due to a combination of factors, namely the previously mentioned low regret, acceptable cost, and due to how they play within the public perception. Evacuation, warning systems, and educational measures are strong performers and carry lower political costs since they have "good" optics and show that the policymakers care about the safety of the end-users, which makes them attractive in the political game. The following statement generalizes this point quite well. Not that " low impact" refers to the fact that warning systems are not extremely noticeable, and most end-users will not consider it a waste (little to no regret).

*Warning systems are easy to sell. Low impact, and they look smart and efficient. Evaluation can follow a similar path.* (From Interviews 3-4)

This attractiveness also comes back to explain why zone management and regeneration perform so poorly, as they either offload responsibility onto the end-users (zone management) or make it appear that the government cannot protect the entire population (regeneration). Evaluation is a special case and lies in the top half of the rankings due to the bias displayed by experts, most of whom work in the

private sector and have common contact with feedback, which is seen as a very positive thing. Experts hailing from governmental bodies consistently mention the challenges of passing evaluation measures through policymakers, as it plays poorly politically, where wins matter more.

Overall, most soft adaptation measures are easier to pass through policymakers than hard measures, owing to their low regret and reduced investment requirement. They also look good politically. Soft adaptation measures that struggle to pass more than hard adaptation measures do so due to unclear benefits or because they do not carry a positive public outlook.

**Social engagement**
The overwhelming majority of soft adaptation measures are generally agreed to perform worse than hard adaptation measures in this criterion, owing to their need to engage the end-user in a significant manner. This is exemplified by the following statements:

*Hard measures don't need engagement, but the end-user that lives or works nearby can be impacted by construction or maintenance nuisance quite a bit.* (From Interview 2)

*Hard measures have low social costs unless you live nearby; otherwise, it has massive social costs.* (From Interview 5)

*Hard measures engage with the end-user through taxes, which are normalized and don't carry significant problems. People see the use of taxes.* (From Interview 6)

The low required engagement from the end-user is also reflected in the administrative measures, which are tied to the lowest social cost with hard adaptation measures. This is explained by the fact that administrative measures are mainly internal institutional measures, with no interaction whatsoever with the general population.

*Warning systems have minimal impact, maybe an app.* (From Interview 6)

*People want to be warned, and they do not care about the admin (keep that backstage).* (From Interview 5)

These statements provide a clear indicator for why warning systems score in the better half of social cost, as they do not require too much interaction with the end user until the warning system is deployed, in which case, the increased interaction is welcomed by the end-user, who wants to be kept informed.

The bottom five performers all share the same aspects: they require much more consistent engagement of the end-user. The nature of this engagement also has a noticeable impact on the social cost, with measures that depend on passive end-user interaction performing slightly better than those requiring active participation.

*Zone management has high social costs, either due to having to understand the new risks or due to having to adhere to new rules and regulations.* (From Interviews 3-4)

*Zone management social costs in the long term will lower aggressively if properly implemented, since it makes the future usage of the zones already adapted to the risks and willing to deal with potential consequences* (From Interviews 3-4)

For example, as shown in the interview insights above, Zone Management carries significant social costs due to the potentially restrictive nature of its measures, but these cost slowly decrease as time passes and the new regulations become known to the end-users, who may decide if they want to engage with them before moving into an area with active zone management policies, such as restrictions. Additionally, the engagement becomes passive once the zone management regulations have been set in place for a while, since the end-users are affected by the measures, but do not have to implement them.

Evaluation follows a similar line of reasoning, where end-users are subject to the testing of systems but do not need to actively test them themselves. The engagement is passive, but carries a higher relative social cost due to perceived annoyance.

Evacuation is an interesting case as it requires very strong active end-user engagement to properly deploy, but only during the specific crisis events. Additionally, end-users are more willing to accept the required engagement as they see immediate benefit. The following insights assist with contextualizing this point.

*Evacuation requires high engagement, but most people might see it as relevant and be willing to endure the extra "workload" since it is a true need.* (From Interview 2)

*Evacuation can be extremely tricky since it strongly depends on whether people consider it necessary. Usually, they do, which makes it easy on the social aspect.* (From Interview 5)

Regeneration ranks poorly in social cost due to the high end-user engagement required to properly implement it. It is of particular relevance since oftentimes, the end-user being engaged is in a vulnerable situation and not able to be engaged in an easy manner.

Educational measures are the clear worst performers when considering the criterion of social cost, and there are multiple reasons for this, exemplified by the following insights.

*Nobody likes to be constantly "educated". They have a high price.* (From Interview 2)

*Education requires active engagement with the end user.* (From Interview 5)

*Only education requires real social engagement. They must be there whether they want to or not.* (From Interview 8)

It is clear that their poor performance arises from the need to have constant engagement with the end-user, and the need for that engagement to be active in order to have the measure succeed, something made difficult by the general disdain from the general population towards education, especially when it is perceived as irrelevant.

Overall, the overwhelming majority of soft adaptation measures carry a higher social cost than hard adaptation measures, arising from their need to engage the end-users, either passively or actively, to be properly deployed. This engagement is made more difficult to realize when the targeted end-user does not see immediate utility in it.

**Cost-effectiveness**

Cost effectiveness represents the only "compound" criterion in the research, as it describes the ratio between the investment in a measure and the resulting benefits it provides, which can come in a variety of ways.

Similar to political cost, soft adaptation measures represent a mixed bag when compared to hard adaptation measures, and this appears to be due to two main reasons, the first of which concerns the following: the type of benefits hard adaptation provides is easier to quantify. This can be seen in some insights from the interviews:

*Hard measures are very easy to quantify; benefits are clear and easy to chart.* (From Interview 2)

*Soft measures are trickier to quantify, literature says they help a lot, practice proves this slightly, but the extent of it is not so [well] understood.* (From Interview 2)

From these insights, it is clear that soft adaptation measures are difficult to quantify, and the reason for this seems to be twofold, in the sense that their benefits are either not immediately apparent, such

as with educational measures, or that their benefits are strongly variable depending on the end-users themselves, such as evacuation. Both of these points are reflected by different soft adaptation measures as shown by the following insights:

*Educational measures are probably efficient, but it does not feel so for the same reason as discussed earlier; the effects are not noticeable instantly. Additionally, the lack of it can be very negative, since it would make citizens completely dependent on the government. Educational measures assist with offloading responsibility to the end user.* (From Interview 6)

*Evacuation in urban areas is not very effective because some people actively ignore the rules. Socio-economic aspects play a role in whether someone does what evacuation plans ask or [sic] instead focus on their personal preferences (families). Culture itself also plays a significant role, with cultures placing a strong emphasis on family ties showing stronger chances of disrupting evacuation orders.* (From Interview 1)

Evacuation is an interesting case since this apparent variability in results has not precluded it from being consistently ranked at the top in terms of cost efficiency, and the reason for this is quite apparent: human lives are deemed as valuable, regardless of their actual "number value". By extension, warning systems perform extremely well, too, since their main benefit is the protection of human life. These thoughts were also shared by most of the experts, with some explicit examples following:

*Evacuation is expensive but saves lives, which is arguably priceless.* (From Interview 2)

*Evacuation is very efficient, plans are cheap, and lives [are] expensive, so it is a good combination.* (From Interview 6)

*Warning systems go straight to the top, [they are] cheap and they save lives.* (From Interview 6)

The difficulty in quantifying the benefits of soft adaptation is also presented in most of the measures that assist with decision-making, which are intended to improve how other measures are engaged, effectively offloading their benefits into other measures, making them more efficient. Examples of this are most noticeable when discussing administrative measures or zone management policies.

*A good decision-making process does not sound sexy. But it has a massive impact on other decisions and can have extremely good consequences down the line. But it does not directly impact anyone, so the benefits are yielded through other measures.* (From Interviews 3-4)

*A lot of measures don't do anything on their own, but they come back to harder measures.* (From Interview 8)

Overall, soft adaptation represents another mixed bag when compared with hard adaptation in the matter of cost-efficiency. The main reason for this is the explicitness of the benefits from the measures, which oftentimes simply have a positive impact on other measures, something that is hard to link back to its source. Additionally, soft adaptation measures don't usually outright eliminate flood risk or completely stop flooding, as hard adaptation measures do, and focus instead on reducing the negative consequences of flooding, which further fuels the lower perceived efficiency. Measures that have a noticeable impact or target the protection of things deemed important, such as human lives, tend to be evaluated highly, even if their explicit benefits cannot be quantified.

**Flexibility & reversibility**

The expectation within this criterion is that soft adaptation measures will noticeably outperform hard adaptation measures, owing to references from previous literature, and this is seen in the overall rankings from Table [D.7].

*Hard measures are not very flexible. [They have a] Long lifetime.* (From Interview 2)

*Hard measures are not flexible when we look at the big-ticket items.* (From Interview 6)

*Hard measures are not that inflexible; they just require [additional] expenses [to modify]. Hard measures are planned with potential flexibility in mind. [Public] Perception is strongly against this one.* (From Interview 8)

While general statements from the interviews support this view of hard adaptation being subject to the highest lock-in, the last insight is very interesting, and it challenges the general perception that hard adaptation measures are not flexible. In practice, this statement does not hold much strength as "everything is modifiable" with enough investment. Hard adaptation is completely focused on physical infrastructure, and this approach will always carry more lock-in than policies, regulations, or plans.

By extension, soft-adaptation measures that have direct connections with infrastructure-based adaptation measures will be subject to more noticeable levels of lock-in. Evacuation, Regeneration, and Zone Management are good examples of this, with the first two having their lower flexibility directly linked to their interconnectedness with infrastructure.

*Evacuation is related to hard measures, which means that you cannot deviate too much from the originally designed routes (the ones that work with hard measures)* (From Interviews 3-4)

*Evacuation is not very flexible since plans take quite a bit to update or change, and they depend on other assets too.* (From Interview 6)

*Evacuation has a lot of preparation, which is not flexible, but the implementation itself is very flexible.* (From Interview 2)

*Regeneration can be split into two things; some have high flexibility (the aftermath policies), others have little (insurance schemes).* (From Interviews 3-4)

These last statements align with the notion that measuring dependence on infrastructure (natural or artificial) correlates with lock-in. Evacuation planning cannot be changed since areas deemed safe are not easily changed, but the implementation of the plans themselves can be quickly adapted to emerging developments. In regeneration, this link is also seen through the low flexibility of insurance policies, which are based on risk categorization, something strongly impacted by infrastructure measures. The policy aspect of regeneration is flexible and can adapt to new requirements much more naturally.

However, the direct relation between lock-in and infrastructure dependence does not preclude the purely policy-based side of soft adaptation measures from being subject to lock-in themselves, something also most evidently demonstrated by zone management policies. Zone management policies are not useful unless enforced consistently for a long period, effectively also being subjected to "artificial lock-in", as the policies can be changed quickly, but they should not, both to remain effective and not disrupt the end-users.

*Zone management has low flexibility due to the massive capital commitments [from end users] and the resistance of the stakeholders involved in potential [subsequent] change in the policy.* (From Interview 3-4)

*Zone management is not flexible since decisions based on it have long-term consequences.* (From Interview 2)

This concept of "artificial lock-in" comes back extremely often, and in plenty of soft adaptation measures. It is clear that most soft adaptation measures are very easily changed and reversed, but doing so often and fast makes them effectively useless and increases the difficulty of future measure deployment, owing to the perceived irritation from the end-users, who will find the institutions handling them incompetent. Some examples of this line of reasoning can be found in the insight logs, with a select few being shown underneath:

*Education can be flexible in that it can be changed, but it should not be, unless you make critical mistakes.* (From Interview 2)

*Similarly to education, warning systems are flexible, but you don't really want them to be changed often, or*

*they lose value.* (From Interview 6)

*Educational measures can be very flexible when thinking about the informational aspect. Things can change fast, and information spreads like wildfire. Information campaigns should be able to keep up if needed. At the same time, education can be inflexible [sic] due to having to unlearn old lessons, which slows it down when subject to change.* (From Interviews 3-4)

*Time is also considered when discussing flexibility. So, education, for example, is at the bottom of the list because it takes a lot of time to change it, not because it cannot be done. You could change the curriculum every 6 months, but you probably shouldn't.* (From Interview 1)

The last two insights provide an additional aspect to consider when looking at flexibility, and that is the aspect of time required to enact the change in the soft adaptation measures. Soft adaptation measures might be cheaper and easier to change, but doing so can take significant amounts of time.

Overall, soft adaptation measures generally show increased flexibility & reversibility when compared to the hard adaptation ones. This increased flexibility does not mean they are completely free from lock-in, but rather that the vast majority of this lock-in can be eliminated, accepting a significant reduction in measure effectiveness. In practical terms, this means that while soft adaptation measures can be changed without too much trouble, they should not be unless it is critically necessary. Small deviations that better align the measures with an ever-changing situation are, however, not problematic and in most cases, encouraged.

### 7.3.2. Final MCDA unweighted matrix

This subsection provides the final unweighted scoring matrix for the seven groups of soft adaptation measures. The scoring reflects a comparative with hard adaptation measures, and displays if the measure performs better or worse than hard adaptation measures in that specific criterion.

Table [7.1] shows the end-result of the qualitative analysis, with a complete matrix that grades every soft adaptation measure category in each of the 5 criteria (interaction is excluded). Measures are given one of three grades for each category:

1. Better: Marked in green, it refers to the measure having a general performance in the criterion significantly superior to that of the hard adaptation measure group.
2. Worse: Marked in red, it indicates that the measure displays a general performance in the criterion significantly inferior to that of the hard adaptation measure group.
3. Blank: Marked in gray, it reflects either a similar performance on the criterion compared to hard-measures, or a difference that is not significant.

Each of the five criteria is individually discussed in the subsequent pages, with a measure by measure breakdown and explanation for the grade. The discussion happens in tables [7.2], [7.3], [7.4], [7.5] and [7.6]. Additionally, the final unweighted scoring matrix includes the main advantages and disadvantages each of the soft adaptation measure categories shows when applied to flooding in the urban sphere.

| | Economic cost | Political cost | Social engagement | Cost-effectiveness | Flexibility & reversibility | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|
| Zone Management | Better | | Worse | Better | | - Very cheap to implement economically.<br>- Extremely cost-effective over long term.<br>- Facilitates planning of other measures. | - Cost is offloaded to the end-users.<br>- Significant lock-in after implementation.<br>- Unpopular if aggressive. |
| Evaluation | Better | Worse | Worse | | Better | - Necessary to stress-test other measures.<br>- Improves overall effectiveness of the systems. | - Very unpopular politically.<br>- Difficult to engage end-users.<br>- Dangerous if poorly deployed. |
| Evacuation | Better | Better | | Better | Better | - Extremely cost-effective.<br>- No need for permanent supplementary infrastructure.<br>- Very popular politically and socially. | - Impossible to deploy in urban spaces without aggresive control.<br>- Does not protect against material damage. |
| Administrative | Better | Worse | | | Better | - Very cheap.<br>- Improves the resilience of the entire system with proper information flow.<br>- Reduces chaos through authority distribution. | - Difficult to pass politically.<br>- Useless if ignored.<br>- Can increase vulnerability if poorly deployed. |
| Warning Systems | Better | Better | | Better | Better | - Cheap and cost-effective.<br>- Popular politically and with easy social engagement.<br>- Flexible and increasing the resilience of the overall system.<br>- Improves planning capabilities through information. | - Requires supplementary infrastructure, the quality of which dictates its utility.<br>- Information needs to be handled properly, or measure becomes useless. |
| Educational | Better | Better | Worse | Better | | - Extremely flexible, capable of adapting to any need.<br>- Cost-effective, albeit with some time to materialize.<br>- Increase resilience of the end-user, and other measures. | - Elevated social engagement, both due to the high quantity, and end-user distaste.<br>- Dangerous if education goals conflict with emerging needs.<br>- Subject to significant lock-in. |
| Regeneration | | Worse | Worse | Worse | | - Accelerates reconstruction and a return to normalcy.<br>- Can reduce subsequent damage from emerging situations. | - Economically inefficient, with risk of total failure.<br>- Unpopular politically due to focus on after the event.<br>- Engagement on extremely vulnerable end-user. |

**Table 7.1:** Final unweighted scoring matrix for the MCDA

| ECONOMIC COST | | | |
|---|---|---|---|
| Measure Group | Score | Justification | Main sources(s) |
| Hard measures | - | Hard measures are generally agreed by the experts to be expensive. Large infrastructure-based projects range in the billions. | - Interview 2<br>- Interview 3-4<br>-(NPR 2019) |
| Zone Management | Better | Zone management is pure policy, with the overwhelming majority of the cost offloaded to the end-user. The more restrictive the zone management, the pricier for the end user. For the authority, the cost is minimal. | - Interview 3-4 |
| Evaluation | Better | Evaluation represents pure policy, and is by extension agreed to be significantly cheaper than hard adaptation measures. | - Interview 6<br>- Interview 8 |
| Evacuation | Better | Evacuation can be split into the policy part and the supplementary infrastructure to support it. Planning is cheap, supplementary infrastructure carries costs, but it is optional. Even if built, the infrastructure is less expensive than equivalent hard measures. | - Interview 3-4<br>- Interview 6<br>- Interview 8 |
| Administrative | Better | Administrative measures is a focused group fully centered around policy. By extension, it is significantly cheaper than hard measures. | - Interview 6<br>- Interview 8 |
| Warning Systems | Better | Similarly to evacuation, warning systems can be split into the warning system itself, and the supporting infrastructure. The infrastructure represents an optional expense and incurs lower costs than the average hard adaptation measure. | - Interview 2<br>- Interview 3-4<br>- Interview 6 |
| Educational | Better | Educational campaigns are generally cheap to run, but the price can rise as the scope grows. Experts agree they typically lie on the cheaper end of the spectrum compared to hard measures, regardless. | - Interview 2<br>- Interview 6 |
| Regenerational | (Blank) | Regeneration is difficult to score due to the inclusion of insurance plans. They are arguably cheaper in theory, since they include pure policy, but when they are engaged costs can skyrocket to a point of making hard adaptation cheap by comparison. To give an example, hurricane Katrina left $125 Billion worth of damages, the subsequent New Orleans seawall system cost $15 Billion. (Dobalian, Claver, and Fickel 2010)<br>A grade cannot be objectively given. | - Interview 7 |

**Table 7.2:** Grade breakdown for economic cost.

| POLITICAL COST | | | |
|---|---|---|---|
| Measure Group | Score | Justification | Main sources(s) |
| Hard measures | - | Hard measures are agreed to lie in the middle when considering political cost. This is due to their proven track record. They are an acceptable option that will work, but will face some struggles due to the elevated investment required. | - Interview 3-4<br>- Interview 6<br>- Interview 8 |
| Zone Management | (Blank) | Zone management is difficult to evaluate objectively due to the differences between levels of government. Local policymakers will consider it their responsibility, but their political cost depends completely on their form. | - Interview 6 |
| Evaluation | Worse | Experts with experience in the political sphere agree that evaluation performs very poorly politically. Politicians dislike evaluation since they focus on what does not work (It makes for bad politics). | - Interview 1<br>- Interview 6 |
| Evacuation | Better | Evacuation does not struggle politically. Due to the focus on saving human lives and the relatively low cost, it carries very good optics politically. | - Interview 2<br>- Interview 3-4 |
| Administrative | Worse | Administrative measures struggle politically, similarly to evaluation. They imply an admission that things could be better and directly impact the administration. Very high risk if they do not work out or are not needed in hindsight. High risk and low reward, politically speaking. | - Interview 1<br>- Interview 3-4 |
| Warning Systems | Better | Warning systems do not struggle politically due to three main factors. They are relatively cheap, they show care for the end-user, and they look smart. They play very well politically and carry little political risk. | - Interview 2<br>- Interview 3-4 |
| Educational | Better | Educational measures are seen as a direct responsibility of the executive. Generally speaking, the political risks lie in the contents, not in the usage of the measures themselves. They are also cheap and carry few political risks. | - Interview 3-4<br>- Interview 5 |
| Regenerational | Worse | Regeneration is tricky to introduce politically, and there is a lot of difficulties related to the implementation of it. Additionally, it can look poorly politically since it incurs an admission that damages will happen. Lastly, their elevated cost means that they tend to struggle significantly in the political sphere. | - Interview 1<br>- Interview 3-4<br>- Interview 6 |

**Table 7.3:** Grade breakdown for political cost.

| SOCIAL ENGAGEMENT | | | |
|---|---|---|---|
| Measure Group | Score | Justification | Main sources(s) |
| Hard measures | - | Hard adaptation measures require almost no engagement with the end-user. There is some interaction in the form of construction and maintenance nuisance. Overall, engagement is minimal and easy to handle. | - Interview 2<br>- Interview 5<br>- Interview 6 |
| Zone Management | Worse | Zone management has a very elevated social engagement. The end-user is effectively responsible for the implementation of the new measures, and they must both understand the new regulations and why they have been introduced. While, over the long term, this required engagement will be reduced, the initial engagement is so significant it cannot be ignored. | - Interview 3-4 |
| Evaluation | Worse | While evaluation does not require a lot of active engagement, it faces the aspect of elevated annoyance for the end-user. Annoyance effectively adds difficulty to the social engagement required. There are some parallels with zone management, but to a much lower scale. It is graded worse to account for the annoyance involved in the social engagement. | - Interview 6 |
| Evacuation | (Blank) | Evacuation is an interesting case, since there is an elevated social engagement during active deployment. This active deployment however, only happens when the end-user is in danger. The perception of utility from the end-user means that this elevated social engagement is actively welcomed. A grade does not include this context; it is therefore left blank. | - Interview 2<br>- Interview 5 |
| Administrative | (Blank) | Administrative measures occur in an environment connected by employment. Their social engagement happens within a workplace (the administration), with direct authority and immediate economic consequences for non-compliance. While there is an elevated social engagement, it happens in a unique environment and cannot be compared to other measures objectively. | - Interview 6<br>- Interview 8 |
| Warning Systems | (Blank) | Warning systems follow a very similar train of thought to evacuation. Social engagement is very elevated during active deployment of the measure, but the engagement is welcomed by the end-user. Since everyday engagement is minimal, a grade cannot be given without losing valuable context. | - Interview 5<br>- Interview 6 |
| Educational | Worse | Educational measures are the clear worst performer in this criterion. Experts all agree that educational measures require extensive social engagement, and that this engagement is perceived negatively. End-users tend to dislike being told what to do. It lies in the other extreme of the spectrum compared to hard measures. | - Interview 2<br>- Interview 5<br>- Interview 8 |
| Regenerational | Worse | Regeneration requires more social engagement that hard measures. This engagement also tends to happen on an end-user that is extremely vulnerable. The required engagement of a vulnerable end-user is the main reason for the poor performance. | - Interview 6<br>- Interview 7 |

**Table 7.4:** Grade breakdown for social engagement.

| COST-EFFECTIVENESS | | | |
|---|---|---|---|
| Measure Group | Score | Justification | Main sources(s) |
| Hard measures | - | Experts and literature agree that hard measures are very easy to quantify. The exact number can vary, but generally speaking, they can be placed at the center. They are expensive but provide noticeable benefits. | - Interview 2<br>- Interview 8 |
| Zone Management | Better | Some experts argue that zone management can be very effective if properly implemented, but that benefits are yielded in the long term. Adding their cheap cost for the administration, they are graded better than hard measures. | - Interview 2<br>- Interview 7 |
| Evaluation | (Blank) | It is difficult to grade evaluation measures, since the benefits provided by the measures are difficult to trace back to the source. | - Interview 3-4<br>- Interview 8 |
| Evacuation | Better | Evacuation is scores better in the cost-effectiveness category due to the perception of human life as extremely valuable (median value of statistical life year is around $170k) (Schlander, Schaefer, and Schwarz 2017). Adding the lower implementation costs, it is graded as a superior performer. | - Interview 2<br>- Interview 6 |
| Administrative | (Blank) | Administrative measures are believed by some experts to have significant benefits, but they are mainly provided in other measures. Like evaluation, it is difficult to grade administrative measures objectively. | - Interview 3-4<br>- Interview 8 |
| Warning Systems | Better | Similarly to evacuation, warning systems primarily target human life and provide valuable information. Their lower implementation cost makes them another superior option ot hard adaptation measures. | - Interview 6 |
| Educational | Better | Educational is generally agreed to be very beneficial by experts, but the precise number of benefits is difficult to break down. The lack of education is also deemed a detriment. This makes educational measures cost-effective. | - Interview 6 |
| Regenerational | Worse | Most experts agree that regenerational measures are some of the most cost-inefficient measures available, owing to their "after the fact" nature. Additionally, the utilization of insurance schemes extracts value out of the system. | - Interview 6<br>- Interview 7 |

**Table 7.5:** Grade breakdown for cost-effectiveness.

| FLEXIBILITY & REVERSIBILITY | | | |
|---|---|---|---|
| Measure Group | Score | Justification | Main sources(s) |
| Hard measures | - | Experts generally agree that hard adaptation measures lie at the bottom of the list when it comes to flexibility & reversibility. They are difficult to change, and any change comes attached to significant economic costs. | - Interview 2<br>- Interview 6<br>- Interview 8 |
| Zone Management | (Blank) | Zone management is difficult to grade. Policy can be easily changed in theory. In practice, the measure becomes exponentially more difficult to maintain and benefits are significantly reduced if change is applied. | - Interview 2<br>- Interview 3-4 |
| Evaluation | Better | Evaluation measures carry the highest flexibility and reversibility due to their event-based nature. Evaluations can be changed or reviewed easily and at low cost, social or economic. | / |
| Evacuation | Better | Evacuation is argued by some experts to not be very flexible, due to the alleged interdependence between hard measures and evacuation routes. This allegation is seen as short-sighted, since the implementation of evacuation plans can be easily modified within some boundaries. They are more flexible than hard measures. | - Interview 2<br>- Interview 3-4<br>- Interview 6 |
| Administrative | Better | Similarly to evaluation, administrative measures remain purely within the internal environment of the administration. They can be easily changed with no extensive costs. They lie around the top of the spectrum. | / |
| Warning Systems | Better | Some experts argue that warning systems are very easily changed, but risk irritation on the end user if abused. Experts showing familiarity with warning systems consistently praise the versatility and adaptability of the measures present. They graded above hard measures. | - Interview 2<br>- Interview 6 |
| Educational | (Blank) | Educational suffers from a similar issue to zone management. Policy can be changed quickly in theory. In practice, it should not. Small changes do not impact the effectiveness too much. It is difficult to justify a grade. | - Interview 1<br>- Interview 2<br>- Interview 3-4<br>- Interview 6 |
| Regenerational | (Blank) | Regeneration could be split into two components. The aftermath policies are highly flexible, while the insurance schemes and regeneration plans are not. Measure is not graded due to this contextual information. | - Interview 3-4 |

**Table 7.6:** Grade breakdown for flexibility & reversibility.

### 7.3.3. Interaction

The results from the qualitative analysis done on measure interaction are shown graphically in Figure [7.1] in the form of a chord diagram. The diagram provides a clear visualization of how often experts mentioned a measure having an impact on others, and which other measures specifically.

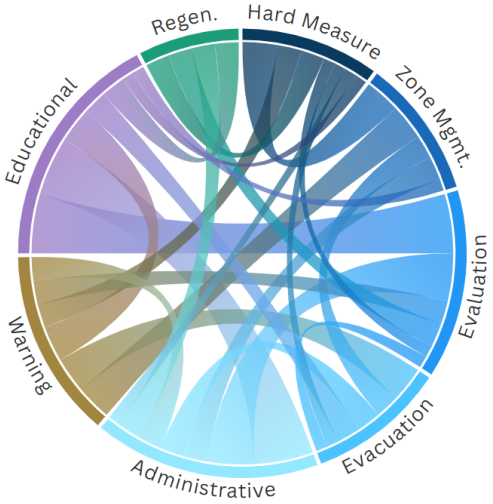



**Figure 7.1:** Chord diagram displaying the interaction links between measures.

Educational measures are the measures most commonly referred to when covering interaction. They are most often paired together with evaluation and administrative measures, but are also mentioned to interact with every other measure at some point.

Administrative measures mimic the results from educational measures and are most often paired with educational and evaluation measures. They are also paired with every other measure, albeit less often.

Evaluation measures are the third most mentioned when discussing interaction, tied with warning systems. They are paired most with educational and administrative measures. They are paired with three of the four remaining options less often. No expert paired them with zone management measures.

Warning systems are tied with evaluation as the third most mentioned measure in the interaction category. They are most often paired with educational, evacuation, and zone management measures. They are paired with every other measure except regeneration at least once.

Zone management measures show a significant decrease in overall mentions from the previous four. They are most often paired with hard measures and warning systems. No expert paired them with either evaluation or regeneration measures.

Evacuation follows as the sixth most mentioned measure during the interaction discussions. The majority of this interaction is with warning systems and zone management measures. They are paired with every other measure except regeneration.

Regeneration is the worst performer not only in overall number of mentions, but in pairings with other measures. Regeneration was only paired with hard measures, evaluation, administrative, and educational measures, evenly spread between the four.

Interaction with hard adaptation measures represents the most compelling aspect of soft adaptation measures in flooding resilience. Plenty of literature on the topic of adaptation consistently revolves around the optimality of utilizing a combination of measures from both the hard and the soft adaptation paradigm. The benefits of this combination can be seen in Figure [7.1], which shows the points of interaction between the adaptation measures used in this research. Soft adaptation measures have a very high interaction not only with infrastructure-based measures, but also with each other.

To better understand what this general interaction entails, it is interesting to delve deeper into individual measure groupings of measures brought up during the interviews and gathered in the insight logs.

*Warning systems will help citizens evacuate to the areas made safe by hard measures and away from those seen as risky through zone management, for example. These measures interact with each other a lot.* (From Interview 1)

*Educational measures can help massively by giving a lot more leeway to other measures. They make end-users a lot more self-sustaining and able to assist with other measures.* (From Interview 7)

From these insights, it becomes apparent that some of the interaction between measures happens through the end-user, who becomes more self-capable and, by extension, is both engaged more readily and more successfully. This interaction, therefore, centers around improving the target of the measures, which, due to the strong dependence on the end-user defined by soft adaptation measures, makes them significantly more effective. The rest of the interaction is related to the decision-making approach, a common point of discussion during the interviews that is best summed up by the following statements:

*Hard measures interact a lot with regeneration since the protected areas dictate where you should invest more in regeneration.* (From Interview 5)

*"Policy measures" work together to influence and improve the "real measures". They mark the way in which you will use the "real measures" to reduce the flood risks.* (From Interview 8)

The distinctions of "Policy" and "Real" are specific context of the interview, with "real" measures including those that directly reduce flooding risk or consequences, while policy measures aim to improve information flow. These assertions directly reference the process of interaction through interconnected

decision making, something that increases the effectiveness of adaptation measures themselves, as they can be better focused.

*Information flows are key; misinformation can have just as much negative impact as no information. Additionally, information flows are usually unidirectional and need more research on how to apply [them] effectively.* (From Interviews 3-4)

This statement brings up a final point of relevance to consider is that interaction is not only positive, but there can be negative aspects to poorly managed interaction, with the most immediate example being disinformation.

Overall, it is clear that soft adaptation measures present strong benefits in the form of positive interaction with other measures. This interaction comes in three main forms:

1. Enhancing the end-user by making it more self-sufficient and informed, which, by extension, makes other soft adaptation measures more effective due to their increased reliance on engagement.
2. Enhancing the measures themselves by aligning their overall approach to account for weaknesses and strengths presented by one another. In simple terms, the sum is better than the parts.
3. Enhancing the decision-making process by facilitating information flow and lessons learned, effectively reducing waste and unnecessary redundancy.

At the same time, this interaction appears to have the potential of being extremely detrimental if not actively managed.

# 8

# Discussion

The following chapter concerns the discussion section of the research. The chapter is internally subdivided into four sections. Section [8.1] covers the first question, section [8.2] covers the second one, and sections [8.3] and [8.4] cover the third and fourth sub-research questions, respectively. Each section is further divided into a result overview, result interpretation, comparison with literature, research contribution, and a research validity & limitations subsection.

## 8.1. Definition of soft adaptation measure

The objective of the first research block was the creation of a new definition for the soft and hard adaptation paradigms. A literature review on the theoretical definition of the paradigms was conducted. Current issues were evaluated to generate a list of objectives for the provided definition. The provided definitions separated the soft and hard paradigms based on the infrastructure utilization of the measure.

**Result interpretation**

The provided definitions for soft and hard adaptation differentiate between the paradigms based on a restrictive approach towards infrastructure utilization:

1. If physical or natural infrastructure represents a central aspect of the measure, the measure is considered to adhere to the hard paradigm of adaptation.
2. If social, economic, educational, or institutional systems represent a central aspect of the measure, the measure is considered to adhere to the soft paradigm of adaptation.

By extension, it is implied by this research that measures cannot be part of both paradigms at the same time. Only one aspect of a measure can be the central one. This division between infrastructure focus or policy focus aligns with the one noticed in relevant adaptation literature, such as the IPCC measure catalog from the fifth assessment report (Noble et al. 2014).

**Comparison with literature**

The proposed definition shows a higher degree of restrictiveness and implies a "one or the other" nature. The nature of the proposed definition shows a clear difference, both in restrictiveness and in classification criteria, with the one proposed by Sovacool (2011); which sees widespread usage. The definition provided by Sovacool (2011) has, however, been subject to criticism from subsequent literature pieces, such as Dolsak and Prakash (2018). The shortcomings detected include the following:

1. The definition of soft adaptation provided by Sovacool (2011) is too general and leaves too much room up for interpretation (Dolšak and Prakash 2018).
2. Sovacool's (2011) distinction between the hard and soft paradigms of adaptation focuses too much on the distinction between natural and artificial infrastructure (Dolšak and Prakash 2018).

**Research contributions**
The proposed definitions for the paradigms address both of the concerns raised by Dolsak and Prakash (2018). This is accomplished in the following manner:

1. The proposed definitions take a more restrictive approach to hard and soft adaptation, and limit the room for interpretation from subsequent users of the definition.
2. The proposed definitions separate adaptation measures along a line employed in general adaptation: infrastructure-based against policy-based.

The proposed definitions delineate the boundaries in a less generalized manner. This could assist with the standardization of the definitions of the hard and soft paradigms in the field by essentially decomposing the categorization down to one question:

*Is physical (artificial or natural) infrastructure a central aspect of the adaptation measure?*

1. If yes, the measure is considered to align with the hard paradigm of adaptation.
2. If no, the measure is considered to align with the soft paradigm of adaptation.

The standardization of the definitions could, by extension, facilitate further research on the soft paradigm of adaptation, by making information easier to locate and by ensuring that consistency between literature pieces is maintained.

The second research block of the thesis (concerning the cataloging of measures) provided a practical example where the proposed definition is put to use. To create the catalog of soft adaptation measures, it was essential to first establish a clear definition of what would be included. The proposed definition served its purpose by eliminating any doubts regarding the classification of the measures.

The proposed definition also saw further utilization during the data gathering stage of the third research block. Experts' prior understanding of the soft and hard paradigms of adaptation was mixed, with some of them voicing doubts about categorization criteria (e.g., what goes in which group?). The provided definition received positive remarks and was argued to be easy to apply and easy to comprehend. It was also essential in setting every interview onto a common baseline prior to any questions.

**Validity and limitations**
The creation of the definition involved the review of previous definitions and their subsequent utilization. Despite these efforts, there are some limitations that remain. They are covered individually.

1. The literature review struggled with the lack of consistency shown by the field. It was common to find soft adaptation defined differently in multiple papers. This challenge, added to the limited amount of time, leaves the chance for relevant sources to have been missed if naming conventions diverged significantly. This could impact the utility of the proposed definitions, since they could display shortcomings identified in the missed literature.
2. The restrictive nature of the proposed definition can struggle with current tendencies. Modern engineering is constantly evolving towards increased interconnectedness between the building blocks that make up projects. This "systems of systems" approach effectively means that modern adaptation measures often include strongly interconnected policy and infrastructure. An example of this interconnectedness could be warning systems. Warning systems can be decomposed into an information system (to disseminate the warning) and an infrastructure system (to monitor the data and trigger the warning). Application of the proposed definition in such a case is subject to challenges, since the measure could be subjectively argued to fit into either of the two paradigms. This limitation introduces additional subjectivity into the classification and could effectively result in the alienation of any measure that is not purely aligned with one paradigm.

## 8.2. Catalog of soft adaptation measures

The objective of the second research block was the compilation of the soft adaptation measures commonly used for flooding, with a focus on the urban environment. A literature review was conducted to identify and compile adaptation measures that aligned with the definitions created during the first research block. These measures were then categorized utilizing archive theory. A total of seven groups of soft adaptation measures were cataloged, included in three overarching categories.

**Result interpretation**

The soft adaptation measure catalog can be consulted in its entirety through table [5.1]. Soft adaptation measures targeting flooding in the urban sphere can be categorized into three overarching groups.

1. Social category, which includes the educational, warning system, and evacuation groups. These measures directly engage the end-user, usually, through information flows.
2. Institutional category, which includes the regenerative, zone management, and administrative groups. Measures in this category target the end-user indirectly and require active participation of the administration (the government).
3. General category, which includes any measures that do not adhere to the previous two categories. Evaluation is included here due to its ability to be used in any context and target anything.

The involvement of the government represents the primary categorization criterion. Social measure groups generally involve the government too, usually in a facilitator role, but their participation is not mandatory. Institutional measures, however, make use of tools only available to the government, such as legislation or policy. The exclusion of evaluation from these two categories implies that this adaptation measure group is more all-encompassing in nature and can take a myriad of forms.

**Comparison with literature**

The compilation and categorization of adaptation measures adhering to the soft paradigm shows some alignment with the compilation and categorization seen in other pieces of literature, with the most notable one being the catalog from the fifth assessment report of the IPCC (2014). Table [8.1] provides a visual description of the alignment.

| IPCC Catalog | | This Research | |
|---|---|---|---|
| Overall Category | Group | Overall Category | Group |
| Physical | Engineering & Built Environment<br>Technological<br>Ecosystem-based<br>Services | Hard measure | |
| Social | Educational | Social | Educational |
| | Informational | | Warning systems |
| | Behavioural | | Evacuation |
| Institutional | Laws & Regulations | Institutional | Zone management |
| | Economic | | Regeneration |
| | Govt. policies & programmes | | Administrative |
| - | - | General | Evaluation |

**Table 8.1:** Alignment between IPCC catalog and this research

From table [8.1] it can be seen that the vast majority of categories from this research have a direct counterpart in the IPCC catalog, with the exceptions of the physical adaptation measures (which are fully grouped into hard measures for the scope of this research) and evaluation, which is not included in the IPCC catalog in an immediately apparent manner.

The IPCC report also discusses that their categorization scheme is not discrete, and adaptation measures could be considered part of more than one category depending on the context. This does not align with the categorization from this research, which is more restrictive and does not consider the categories to be open to contextual interpretation.

**Research contributions**
The categorization scheme provided in this research provides a standardized approach to compile soft adaptation measures used to target flooding in the urban space. The categorization scheme can be understood through the utilization of the following questions.

1. Does the adaptation measure involve regulatory tools such as laws, government policy, or economic incentives?

   (a) If the answer to this question is yes, the measure goes in the institutional category.
   (b) If the answer to this question is no, the measure goes in the social category.

2. What area of flooding adaptation does the measure focus on?

   (a) If a sub-category focused on such an area already exists, the measure is grouped into it.
   (b) If no sub-category focuses on such an area, create a new one with an appropriate name.

The simple nature of these questions could facilitate decision-making by allowing policy-makers to easily locate measures in the catalog. Locating measures already categorized follows an identical process to categorizing them in the first place. Utilization of the catalog by an end-user relatively informed of current organizational practices should not be challenging, owing to the alignment with commonly cited examples such as the IPCC scheme (2014). The revised sub-category names could also prove useful when the end-user of the catalog is uninformed of currently accepted naming practices. Additionally, the end-users could more easily understand what groups (also referred to as sub-categories) do at a first glance due to the sub-category names being example-based.

The third block of research utilized the cataloged groups (or sub-categories) of measures as a central resource. Overall opinion was positive, and the majority of experts argued that the groups cataloged in this research reflected their experiences well, with no immediately noticeable gaps.

**Validity and limitations**
The creation of the soft adaptation measure catalog involved extensive work on a second literature review and saw significant application of archive theory to maximize effectiveness. Some limitations need to be considered. They are covered individually

1. The literature review struggled, once again, with the lack of consistency shown by the field. This struggle is noticeable in other pieces of literature aiming to compile measures, too. Sources such as the IPCC catalog (2014) mention the unlikelihood of naming conventions showing consistency between sources. This issue is further expanded to the way adaptation measures themselves are named. Such a challenge introduces the non-trivial chance that pieces of information have been missed. The catalog provided in this research, therefore, represents a non-exhaustive piece of work.
2. Sub-categories remain subject to a degree of subjectivity on the part of the end-user. By extension, it can be argued that overlap between categories remains a limitation of this catalog. This potential overlap was directly brought up during practical utilization of the sub-categories by one of the experts. Their argument was that they considered insurance to potentially be a part of zone management. This potential for overlap could become a larger limitation as the catalog is expanded and new sub-categories are introduced.

## 8.3. Advantages and disadvantages of soft adaptation measures

The third research block aimed to evaluate the soft adaptation measure groups in six different criteria. Data for this evaluation were gathered through a set of 8 semi-structured interviews. The interview targets comprised experts selected across layers of society with an active interest in flooding. The resulting data from the interviews were evaluated through a multiple-criteria qualitative analysis. The results from this analysis indicate that soft adaptation measures generally outperform hard adaptation measures in terms of economic cost and flexibility. It also argues that soft adaptation measures underperform in terms of social engagement. The last two criteria, concerning political cost and cost-effectiveness, are mixed and vary between the individual measures.

**Result interpretation**
The final MCDA table (7.1) from Chapter [7] provides the advantages and disadvantages of the groups of soft adaptation measures, together with a comparative description of whether they perform better or worse than hard adaptation measures in multiple criteria. Soft adaptation measures appear to generally perform better or similarly to hard measures in two categories:

1. Flexibility and reversibility: Soft adaptation measures appear to show superior flexibility compared to hard measures. This appears to be due to their dependence on policy. The aspect of flexibility implies that soft adaptation measures can, for the most part, be easily changed. When changed, they generally do not appear to carry significant costs. The reversibility aspect argues that there is a low risk of regret if the measure turns out to be unnecessary.
2. Economical cost: Similarly to the previous criterion, their focus on policy over infrastructure appears to be the main cause for their lower average economic cost. From the analysis, it is argued that implementation costs are primarily related to supplementary infrastructure requirements. Additional infrastructure requirements, therefore, tend to carry increased economic costs.

Table [7.1] also shows the criteria where soft adaptation measures perform worse or in a mixed manner when compared to hard adaptation measures.

1. Political cost: The analysis indicates that soft adaptation measures represent a mixed bag when compared to hard adaptation measures in this criterion. Evaluation, administrative, and regeneration perform worse than hard measures. This appears to be due to the optics surrounding the measures, since the government admits inability to protect or imperfection that must be evaluated/corrected. By extension, measures that appear smart, efficient, or display care for the end-user are shown to score better than hard measures. The analysis, therefore, argues that there is a direct relation between the optics of a measure and how likely it is to garner political support. These optics appear to also involve the implementation costs and the expected benefits.
2. Social engagement: Over half of the soft adaptation measures score explicitly worse than the hard adaptation measures in this criterion. Despite this, the analysis argues that all soft adaptation measures carry a higher social engagement than hard adaptation measures. This effectively transfers responsibility from the government to the end-user. This engagement appears to mainly be negative, in the form of an annoyed end-user who must add things to their list of responsibilities. In some emergency situations, the engagement appears to be tolerated or even encouraged by the end-user, indicating that during risk events, end-users are willing to accept additional engagement. Social engagement also appears to be a large contributor to why soft adaptation measures cannot be described in a discrete manner prior to implementation.
3. Cost-effectiveness: Most soft adaptation measures perform better in this criterion than hard adaptation measures, with the exceptions of regeneration, evaluation, and administrative measures. The increased cost-effectiveness appears to be primarily linked to the lower implementation costs shown by soft adaptation measures. Evaluation and administrative measures lack a score due to difficulties quantifying their effectiveness (in practical terms, their benefits). Regeneration appears to perform poorly due to its elevated active deployment costs. Overall, the analysis shows that cost-effectiveness is challenging to objectively grade.

**Comparison with literature**
The analysis from this research concerns the performance of soft adaptation measures on multiple criteria. They are covered individually.

1. Soft adaptation measures performing generally better in flexibility & reversibility align with previous literature. The 2009 analysis by Hallegatte had adaptation measures marked as soft performing showing good performances in the criteria of flexibility, robustness, and reversibility (Hallegatte 2009). The 2011 definition from Sovacool also discusses the soft adaptation path being subject to higher relative flexibility than the hard adaptation path (Sovacool 2011). The increased flexibility & reversibility also align with the 2020 analysis from Baills et al. Baills' "complimentary measures" match the composition of the soft adaptation group and outscore every other category in the criteria of flexibility, reversibility, and no-regret (Baills, Garcin, and Bulteau 2020).

2. Soft adaptation measures show superior performance in the criterion of economic cost, owing to their focus on policy over infrastructure. This is expected and shows alignment with the original definitions from Sovacool (2011), which describe the soft adaptation path as simpler and cheaper than the hard one. The 2020 analysis from Baills et al. provides similar findings, but limits the comparison to ballpark figures, with little justification behind them (Baills, Garcin, and Bulteau 2020).
3. Soft adaptation measures show varied performance on the political cost criterion. This performance is implied to link with the optics behind a measure and the difficulty of quantifying the benefits (which effectively makes the measure hard to defend). These results directly align with those from previous literature, where it was argued that soft adaptation measures struggle politically due to quantification challenges and political games (Dolšak and Prakash 2018).
4. The overwhelming majority of soft adaptation measures involve increased engagement from the end-user. The results from this show some alignment with previous literature, where it is argued that the benefits of soft adaptation measures are co-produced with the end-users (Parks et al. 1981; Bovaird 2007). The topic of social engagement does, however, receive lower coverage in the engineering academic field. This lower coverage appears to be due to the need to transition from engineering sciences towards social sciences (Baills, Garcin, and Bulteau 2020).
5. For the cost-effectiveness criterion, the analysis shows that soft adaptation measures represent a mixed group compared with hard adaptation measures. Previous literature does not discuss the concept of cost-effectiveness, and argues about the challenges of quantifying the effectiveness of soft adaptation measures instead (Dolšak and Prakash 2018). Some previous analyses struggle with criteria related to the effectiveness of measures, such as the timeline until results are yielded (Baills, Garcin, and Bulteau 2020). This challenge is mirrored in this research, too, with effectiveness estimation remaining the main limiting factor to cost-effectiveness evaluation.

**Research contribution**

The multi-criteria analysis from this research strengthens some of the assertions made by previous literature and expands on them by introducing new considerations. This could be argued to have a positive impact in two main ways.

1. The soft adaptation field should benefit from the apparent confirmation of the most commonly used assertions. This confirmation could be further explored through the expansions provided in this piece of research. This should assist future research by providing more data and introducing new relevant aspects.
2. The specific focus of the multi-criteria analysis on flooding in the urban space should benefit policy-makers in this sphere with decision-making. The "unsolved" nature of the scoring matrix should allow decision-makers to tailor the analysis based on their specific criterion preferences. Additionally, the inclusion of benefits, negatives, and aspects to consider when implementing each soft adaptation measure should have a positive impact on future implementation decisions by introducing context lost in pure scoring analyses.

**Validity and limitations**

The format itself is worth discussing prior to the general limitations, due to the strong influence of the lines of questioning on the flow of the conversation. The lines of questioning represent the structured sections and are, by extension, more rigid. Despite individual peculiarities, all interviews transpired in a similar way due to the strong railroading induced by the structured sections. To compensate, experts were given the option to deviate from the agreed topics at their discretion; most did to a certain degree. Additionally, every interview had a final section where experts were asked if something important had been missed; no experts believed something of high relevance had been ignored. These steps aimed to minimize the chance of missed aspects and allow for the exploration of additional insights and/or experiences. There were some practicalities on how interviews were conducted, of which two are considered relevant for discussion:

1. One of the interviews included sections where two experts debated with one another. This represented a risk of bias or agreement on social pressure, akin to a Delphi method to research (Dalkey and Helmer 1963). The Delphi method has been criticized for its inherent bias and forceful

approach to agreement. This ended up not happening, and the experts shared thoughts on their reasoning but remained confident in their original rankings. Overall, there was limited utility in the context of this research to having both experts discuss, as they had different backgrounds and, by extension, different points of view. It did serve as an educational experience for both of them and facilitated the conduct of the interview.

2. One of the interviews happened in person, while the rest of the interviews happened in a digital medium. This represented a significant worry initially, due to the cards and general interview format being designed for the physical medium (to play with the cards). Some interviews were, however, immediately scheduled online by part of the experts. Therefore, a digital playboard was created to substitute the physical play set, with digital cards simulating a real desktop. This resulted in differences between physical and digital interviews becoming minor, as experts remained able to engage with the cards themselves, regardless of the medium. Additionally, the ability to interview digitally allowed the experts the chance to talk in a comfortable environment, similar to an interview that happened in person.

Overall, however, the results from table [7.1] are subject to some limitations that need to be discussed. They are the following:

1. Sample size: Most of the data used in the qualitative analysis arises from 8 experts, which is a small sample size. The research accounted for this limitation by trying to contact a large number of experts (25) during the data gathering phase. As visible in figure [6.8], there was a considerable drop-off (70%) in the final results. The eight final participants represent, however, a varied group, with participation from almost all layers identified in table [6.4]. Despite this, some layers were still not represented in the final interview lineup. This caused some spots in the final analysis matrix (table[7.1]) to remain blank. It could also limit the depth of the results and increase the risk that the data gathered represents an unrealistic representation of the general field.
2. Result extrapolation: With 7 of the 8 experts hailing from the Netherlands, their experiences are directly impacted by the environment in the country, including the organizational culture and current infrastructure. Some experts even went as far as to mention statements along the lines of "this is not relevant in the Netherlands", showing the level of bias present in the interview process. This is not unexpected, and previous analyses of adaptation measures have avoided involving local stakeholders to sidestep this issue completely. Baills et al. (2020) make this exact statement, aiming to keep their results general enough to be extrapolated. They admit, however, that involving local stakeholders is necessary to get results that are applicable to any real-life scenario. This research chose to involve local stakeholders, and this would, in theory, make the results less applicable to countries outside of the Netherlands. The involvement of a stakeholder from Spain eases this problem, but only slightly. A single opinion cannot be considered representative, and there is a significant risk that it reflects a simple coincidence. General extrapolation of the results to other environments represents, therefore, one of the most significant limitations of the research.
3. Missed aspects: There were some criteria commonly used in other literature pieces that were not discussed in this research. The main one is the timescale until adaptation measures yield a return. This criterion is used in one way or another in other pieces of research, such as Baills et al. (2020) or Hallegatte (2009). This research excluded it from the discussion owing to the limited time available. Additionally, previous research has struggled with the application of this criterion to soft adaptation measures themselves. This struggle appears to originate from the challenges in quantifying soft adaptation measures. This challenge is, however, discussed in this research, with the focus being on cost-effectiveness. Despite this, the exclusion of such a criterion cannot be understated, and it remains a significant limitation of this analysis. Additional limitations are linked to the utilization of local stakeholders. This project contacted local stakeholders, but the focus of the interviews remained on the engineering side of measures. Social sciences lie outside the scope of this project, and this significantly increases the risk that aspects related to social criteria have been missed.

## 8.4. Interaction between adaptation measures

The final section from chapter [7] aimed to chart and better understand the ways in which adaptation measures interact with one another. Similar to sub-research question 3, the data was gathered through the same 8 semi-structured interviews with experts. The resulting data could be analyzed through the MCDA. It was instead evaluated qualitatively by recording explicit mentions of measure interaction. The results indicate that soft adaptation measures have extensive interaction with one another, and that all of them interact with hard adaptation measures.

**Result interpretation**

Figure [7.1] shows the interaction pairings gathered from the qualitative analysis. While they vary per measure, all soft adaptation measures interact with hard adaptation measures. Their interaction between themselves is more varied, with some measures having strong interaction and others not interacting at all. This interaction appears to come in three main ways:

1. Raising social capital: Most soft-adaptation measures are argued to have an impact on the end-user, by making them more self-sufficient and increasing their social capital. This increase in social capital appears to extend to other measures, facilitating subsequent engagement. Overall, this can be argued to mean that positive engagement from one measure will improve the quality of subsequent engagement.
2. Aligning measures together: Some of the interaction between measures appears to originate from their potential for cohesion. This directly implies that positive interaction from soft adaptation measures can transform a set of disjointed measures into a cohesive unit, working in tandem to achieve a result superior to the sum of its parts.
3. Enhancing the decision-making process: Many of the soft adaptation measures deal with information or planning prior to crisis events. Logically, this ought to translate into improved decisions, both due to more information availability and due to increased cohesion in the decision-making.

**Comparison with literature**

The results of this research show that soft adaptation measures have high interaction, easily visualized through figure [7.1]. Interaction connections can be detected in a straightforward manner, and it is argued by the research that the majority of it is positive. The mechanics of this interaction are, however, more subject to interpretation. This aligns with the general statements issued from previous research, where it is argued that optimal adaptation should involve measures from both paradigms (Dolšak and Prakash 2018; Sovacool 2011). Other pieces of literature focus instead on the topic of synergy with mitigation (Hallegatte 2009; Noble et al. 2014; Baills, Garcin, and Bulteau 2020). This focus on synergy with mitigation is argued by this research to be a reductionist approach to measure interaction. Additionally, this research decomposes interaction into three main types, which do not receive explicit coverage in other research but show some alignment:

1. Raising social capital: This is a logical extension that aligns with some of the reasoning shared on soft adaptation through Dolsak and Prakash (2018). If the end-user co-produces the benefits of a soft adaptation measure (Parks et al. 1981; Bovaird 2007), it stands to reason that this will also extend to the co-production of benefits from other measures.
2. Aligning measures together: This is in direct agreement with general statements discussed in previous research. Specific examples include the comparison to the "hub-and-spokes" system from Dolsak and Prakash (2018) or the discussion on social and institutional measures from the IPCC fifth report (2014). The categorization as "complementary" in Baills et al. (2020) carries some alignment with the findings from this research, but places them in a minor role behind measures that are argued to be "real". This also applies to the following finding.
3. Enhancing the decision-making process: The distinction from Baills et al. (2020) makes more sense in this context. Baills et al. (2020) argue that "complementary" measures enhance "real" measures by increasing the information available prior to their implementation. This directly aligns with the findings from this research.

**Research contribution**
The results from the qualitative analysis on interaction show that soft adaptation measures interact with one another extensively, and that this interaction is primarily positive. In the majority of cases, this interaction also extends to include hard adaptation measures. The benefits of such findings are, similarly to the ones from sub-research question 3, divided into two main pathways.

1. The adaptation field stands to benefit from the expansion on the topic of interaction, which has received limited coverage. This introduction of multiple types of interaction should open new pathways of research on soft adaptation measures. By extension, it could ease the challenges relating to the quantification of measures, of which the interaction between measures remains a significant one.
2. Policy-makers also stand to benefit from the expansion of interaction. This benefit materializes by providing them with a better understanding of what their soft adaptation measures entail. Additionally, it could facilitate with implementation of additional measures (related or unrelated to flooding adaptation) due to the end-user enhancement aspects of interaction.

**Validity and limitations**
The interaction pathways and connections between soft adaptation measures were obtained through a focused qualitative analysis. The analysis itself involved the same data gathering approach utilized for sub-research question three. Therefore, most of the limitations discussed during section [8.3] also apply to the results for this qualitative analysis. Additionally, the results for interaction carry two additional important limitations to discuss:

1. Social phenomena related to the end-user: It is apparent that the end-user has a very strong impact on interaction, and soft measures as a whole. Properly understanding interaction would require an in-depth socio-cultural analysis well outside the scope of this research project. Unlike Baills et al. (2020), which avoided the social aspect completely, this research delved into the topic further, albeit still nowhere close to the one required for a full study involving social sciences, as argued by Boruff, Emrich and Cutter (2005). A proper study on end-user interaction with measures would involve significantly more end-users, with distinctions for cultural and socio-economic background, age groups, etc. Therefore, there exists a significant risk that the results of this qualitative analysis lack nuance or provide a superficial evaluation of the social dynamics involved in soft adaptation measure interaction.
2. Spatial interaction: Despite the mentions of measures aligning in their strengths and benefits, the spatial aspect of interaction is not explicitly considered. Spatial relationships (or how measures share the physical space) arguably represent an integral aspect of measure interaction. The nature of the interaction between measures has a spatial aspect that should be accounted for to best understand how measures align their strengths or cover each other's weaknesses. The limited time available for the research led to this topic being considered outside of the scope. This arguably limits the depth of the interaction results between measure alignment. Future research is recommended to account for the physical space when researching the topic of interaction further.

# 9

# Conclusion & recommendations

This chapter encompasses the conclusion of the research, where the sub-research questions are formally resolved concisely. These sub-research questions are then used to answer the main research question driving the research:

*How can soft adaptation measures affect resilience to floods in an urbanized environment?*

The chapter is internally split into three sections. Section [9.1] covers the answers to the sub-research questions. Section [9.2] provides the answer to the main research question. Lastly, section [9.3] provides some recommendations for future research.

## 9.1. Answering sub-research questions

**What exactly constitutes a soft-adaptation measure?**
Adaptation measures are said to be part of the soft paradigm when they rely on social, institutional, educational, or economic policy. Their performance cannot be predicted prior to implementation due to their interaction with the end-user, which is either mandatory or strongly required, and the nature of which has an impact on their utility. It adheres to the mentality of "changing societal approaches to environmental needs".

On the other hand, adaptation measures are said to be part of the hard paradigm when they are centered around infrastructure, whether natural or artificial. Their performance can be accurately predicted before implementation. There is little to no interaction with the end-user, and the utility of the measure has no relation to it. It adheres to the mentality of "bending the environment to societal needs".

**What types of soft adaptation measures are commonly used in flooding?**
For flooding, soft adaptation measures can be categorized into one of seven general groups, each based on a different strategy but all aimed at increasing the flooding resilience in one way or another. They include:

1. Warning Systems: These measures focus on providing warnings and predicting damages before crisis events, intending to reduce damages
2. Zone Management: These measures focus on the assessment of vulnerable areas and the development of subsequent regulations to reduce their vulnerability.
3. Evacuation: These measures focus on the movement of people and assets away from dangerous areas during crisis events. They aim to save lives and limit damage.
4. Administrative: These measures focus on the information flow and governance structure within governmental organizations. Their goal is to reduce over-dependence and, by extension, limit additional chaos-induced damage.
5. Regeneration: These measures aim to stimulate the reconstruction and regeneration of damaged areas after crisis events. They aim to speed a return to pre-event normalcy.

6. Educational: These measures focus on disseminating knowledge to increase end-user knowledge. They aim to limit damage by fostering self-reliance and better engagement with other measures.
7. Evaluation: These measures review and test the implementation of other measures, to ascertain what works and what does not. They aim to increase the effectiveness of other measures.

**What are the advantages and disadvantages of each of these measures?**
Soft adaptation measures present general advantages over hard adaptation measures in the following aspects:

1. They carry lower economic investment, both initial and long-term. This low cost originates from either a lack of required investment in traditional physical infrastructure, or by offloading part of the costs to the end-users, effectively spreading the costs out. This advantage in cost shrinks quickly when the scope and complexity of the measures increase.
2. They are much more capable of changing to fit new requirements or adapting to emerging situations. This arises from their lack of infrastructure-based lock-in. This allows them to be modified to better align with flooding resilience objectives as requirements evolve or needs become critical. This increased flexibility carries negative consequences when abused, so it should be used sparingly.
3. They enhance other measures by interacting with both the end-user, a common aspect of most soft-adaptation measures, and other measures themselves, including infrastructure-based ones, effectively inducing positive resonance in overall measure effectiveness.

Despite these advantages, soft adaptation measures also present some clear general weaknesses when compared to hard adaptation measures, such as:

1. They can struggle getting through legislative bodies, due to their perception as "useless expenditure" or "needless red tape". This perception is particularly poignant when the benefits are not reaped immediately, or the measures play poorly in the public view.
2. They require significant end-user engagement, depending strongly on the nature of this engagement to reap any benefits, something unheard of for hard adaptation measures. This end-user engagement makes them more labor-intensive to deploy and requires constant monitoring and evaluation. This engagement is made additionally challenging when the end-user does not believe in its utility.
3. Their effectiveness (and subsequent cost-effectiveness ratio) is difficult to quantify since it usually comes back in other measures or after a long time. This challenge on quantifying them makes it difficult to justify their investment when compared to hard adaptation measures. Some notable exceptions include soft adaptation measures directly aimed at protecting human lives, something deemed of maximum value.

The specific advantages and disadvantages of each of these measures are displayed in table [7.1].

**What is their interaction with themselves? And with hard measures?**
Soft adaptation measures present interaction in three main ways. All three of these interaction aspects can happen between soft adaptation measures, while only the last two can apply to interaction between soft and hard adaptation measures.

1. They can enhance the end-user by making them more self-reliant, which facilitates and enhances engagement from other adaptation measures.
2. They can align measures together, effectively creating a sum of measures that work in unison. This makes it possible for measures to rely on each other's benefits and cover each other's shortcomings.
3. They can increase the information available for decision making, effectively providing a more complete picture and reducing unnecessary redundancy or waste.

This interaction has to be actively managed, as it has the potential to be disastrous if handled poorly, creating direct conflict between measure alignments and acting as a dissonant force.

## 9.2. Answering the main research question

With the sub-research questions covered, it is possible to provide an answer to the main research question.

*How can soft adaptation measures affect resilience to floods in an urbanized environment?*

Soft adaptation measures, defined as those that rely on social, institutional, educational, and economic policy, can have a noticeable positive impact on flooding resilience due to three main reasons, centered around interaction with other adaptation strategies:

1. They encourage the alignment of strengths and weaknesses from different adaptation measures, which directly increases the overall effectiveness in the adaptation portfolio. This alignment is also present in decision-making, as soft-adaptation nurtures the sharing of information and strengthens the governance structure.
2. They provide additional layers of protection, effectively creating a multi-layered strategy and reducing the risk of dire crisis-event-induced consequences if traditional infrastructure-based adaptation fails.
3. They offload responsibility away from government and policymakers onto the end-user, raising their social capital and facilitating future engagement, which makes the populace itself more resilient.

Soft adaptation measures also offer several general advantages over traditional infrastructure-based adaptation:

1. Lower economic costs: Their focus on policy allows policymakers with limited resources to include other measures on top of the soft adaptation ones, effectively increasing the range of options.
2. Lower lock-in: Policies are flexible and can be changed rapidly if needed. This allows for measures to remain useful with uncertain climate predictions, delaying more restrictive options open for the future.
3. Lower regret: Due to their benefits being co-produced with the end-users, soft adaptation measures carry positives in other measures/policies even if they never end up not being used themselves.

They do, however, carry some significant weaknesses that must be accounted for, especially since they are unique to soft adaptation measures:

1. Required positive engagement: Due to their strong connection with the end-user to reap benefits, engagement and monitoring must happen consistently. This engagement has to be positive, and risks negative consequences if poorly managed, potentially reducing resilience. This can present challenges to policymakers will limited (human) resources or with limited engagement to their end-users (cultural or educational barriers).
2. Political struggle: Soft adaptation measures can struggle politically due to their unpredictable nature. The difficulty to directly link the benefits to the measure itself also increases this issue. Politically unstable environments will steer away from them due to the difficulty to justify them.
3. Inability to stop flooding: Their focus on policy as opposed to infrastructure limits the impact to reducing damages from flooding, but not to stopping the flooding itself. The only soft adaptation measures capable of directly avoiding flooding are aggressive zone management or migration. They are unfeasible and unrealistic in most large-scale urban environments, and only taken as a last-resort when all other options are exhausted. Therefore, most policymakers will prioritize hard adaptation measures, with some soft adaptation as backups (evacuation or regeneration).

Soft adaptation measures are therefore very suitable for reducing flooding damage in the urban environment, but their limitations must be considered. The optimal way to use soft adaptation measures is in conjunction with hard adaptation (infrastructure based). This implementation along hard measures allows for them to cohesively protect the urban space against and flooding and increase overall resilience.

## 9.3. Recommendations for future research

While this research provides a first step towards creating a consistent definition for the paradigm of soft adaptation, the scope remains, for the project, fixated on flooding resilience in the urban environment. There is a significant benefit to be gained by reviewing the definition further and extrapolating it to the general adaptation field. The adaptation field is evolving very fast, and the distinctions between the hard and soft paradigms should evolve with it in order to remain useful and clear.

The topics of end-user engagement and social capital, reflected in this research through the criterion of social engagement, also represent an interesting pathway of future research. From this project, it is apparent that end-user engagement is an extremely complex concept subject to significant context, and it has a very strong connection with adaptation measures in the soft paradigm. Positive engagement leads to improved measure efficiency and better receptiveness to subsequent engagement, which in the literature is denoted as increasing the social capital. The interesting aspect of the topic concerns the opposite situation, where negative end-user engagement has a detrimental impact on soft adaptation measures. Additionally, as positive engagement leads to a population more receptive to future engagement, it could lead to a significant decrease in overall resilience due to the risk of misinformation being introduced into the system when the end-user is very receptive. The mechanics of this exacerbated negative effect are not immediately apparent from this research, mainly due to its scope limitations on social phenomena. It would be beneficial for future research to further explore the concept and try to better understand what exactly the positive and negative connotations of increased social capital are, and if increased social capital is always a positive aspect.

Lastly, the topic of interaction, with either end-users and between adaptation measures themselves, garners significant attention when considering future avenues of investigation, due to it being identified as the main source of benefits that soft adaptation measures use to increase flooding resilience. This research identified three forms of interaction, but the specific nature of it remains poorly understood. While the research identified these pathways of interaction, there is a very strong contextual connotation to their underlying mechanics, and many of them arise from the uniqueness of governance structures in the Netherlands. Additionally, there is the concept of potential negative interaction between measures, something discovered by this research. There would be a significant benefit to expand on the concept of adaptation measure interaction in flooding in order to understand how exactly it works, how its benefits can be maximized, and how negative interaction can be minimized. This expansion on the topic of measure interaction would involve extensive work with end-users and flooding adaptation stakeholders. The majority of the work would lie outside of the scope of engineering research, delving deeper into social studies instead.

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# A

# Unstructured Discussion Insight Logs

ECONOMIC

- Economic ranking also works for the long term. A lot of the administrative tools already exist and not much needs to be fundamentally changed. It's paperwork or pure policy discussion. Flexible and easy to adapt to new needs.
- Evaluation is relatively new; oftentimes governments jump directly from action to action without having too much time to reminisce or review everything. Time is money, which makes evaluation surprisingly expensive.

POLITICAL

- Political costs do not change too much with time. Most politicians in R'dam agree on the importance of water and climate safety. It is a bit of a non-political issue when money used is not absurd.
- Politically, a lot of the measures do not need to be revisited in the political sphere. Just keep costs low.
- Regeneration is tricky due to the preferences of each party on how to do it.
- Negative views on feedback and evaluation due to political games. Evaluation tends to focus on what did not work, which does not play nicely in the politics game, where you want to focus on your wins. People don't like it much.
- Even checking out if invested money did something, is not a guarantee in the R'dam system due to their aversion to feedback.

SOCIAL

- Every month water and fire emergency alarm systems are tested in R'dam, and people take them very seriously.
- Nothern to Southern Europe, people in the North are a lot more willing to follow government policies or recommendations than people in the south.

EFFICIENCY

- Education is not effective instantly, but consistent investment scales exponentially, even beating warning systems. People will know what to do without needing to hear it from a warning system.
- Evacuation in urban areas is not very effective because some people actively ignore the rules. Socio-economic aspects play a role in whether someone does what evacuation plans ask or instead focus on their personal preferences (families). Culture itself also plays a significant role, with cultures placing a strong emphasis on family ties showing stronger chances of disrupting evacuation orders.
- World events happening at the time of the crisis influence how likely people are to follow government directives.

FLEXIBILITY

- Time is also considered when discussing flexibility. So, education, for example, is at the bottom of the list because it takes a lot of time to change it, not because it cannot be done. You could change the curriculum every 6 months, but you probably shouldn't.
- Political games do not influence the flexibility picture if the topic is considered “crisis” level. In these crisis situations, the administration acts first and then justifies it to the parties. This is agreed in advance with the parties. They want the problem solved ASAP, before discussing the details.

INTERACTION

- Warning systems will help citizens evacuate to the areas made safe by hard measures and away from those seen as risky through zone management, for example. These measures interact with each other a lot.
- Evaluation is important but has no real interaction when actions are very time sensitive.

GENERAL

- Governance structure is important. Decentralization in the R'dam government is worthy of study. When decentralized, communication is extremely important, which makes administrative measures more important. (Who are you to tell me what to do?). The best way is to structure authority for crisis events.

ECONOMIC

- Hard measures are quite expensive, especially in the short term. On the long term it might be cheaper, but in general it is pricy. Maintenance is significant and expensive; shelf life is also relevant.
- Educational campaigns are typically cheap and cost effective. On a low level (low penetration or size), they can be implemented quickly and cheaply.
- Warning systems can be quite cheap depending on the scale (100k for example), but as you increase the scope, they get more expensive, fast. Overall, they are still cheaper than the average measure.
- Zone management is cheap from the administrative side. The biggest part comes from enforcing it.
- Evacuation is expensive, on the level of hard measures.
- Evaluation is comprised of cheap steps, like simulations.
- Software is expensive because it must be updated very often due to evolving technology, but it remains lower than your harder measures.

POLITICAL (Not an expert on the topic)

- Economical cost is part of the political cost. Expensive things are harder to pass, regardless of their efficiency.
- In general, policies are more likely to pass if they have a low impact on the community, such as evaluation or educational campaigns (no regret options). Zone management is more aggressive on the end user, warning systems are not well understood, and hard measures are agreed to be expensive, making them less likely to pass.

SOCIAL

- Nobody likes to be constantly “educated”. They have a high price.
- Hard measures don't need engagement, but the end-user that lives or works nearby can be impacted by construction or maintenance nuisance quite a bit.
- Evacuation requires high engagement, but most people might see it as relevant and be willing to endure the extra "workload” since it is a true need.
- The scale of the measure has a strong impact on social costs. Larger scales imply more nuisance.

EFFICIENCY (Tricky to answer) (Final ranking is done on cost-effectiveness)

- Hard measures are very easy to quantify; benefits are clear and easy to chart.
- Soft measures are trickier to quantify, literature says they help a lot, practice proves this slightly, but the extent of it is not so understood.
- Multilayer approach can mean that later parts of the system will always be more efficient since they are engaged only when everything else has failed (Evacuations are very high in the ranking because of this)
- Zone management is underappreciated, and it can help a lot if properly implemented. Warning systems are the same.
- Evaluation is difficult to get going and properly implement, which limits efficiency.

- Regeneration is like evaluation, but even worse (Limburg for example with money gone unspent or poorly allocated).
- Evacuation is expensive but saves lives, which is arguably priceless. However, the government does not pay a bill for every death, which creates a strong dichotomy between private and public.
- Hard measures are extremely effective, but their cost-effectiveness is not as good due to the high price tag. They are the "safe option" for a lot of policymakers.

FLEXIBILITY

- Hard measures are not very flexible. Long lifetime.
- Evacuation has a lot of preparation which is not flexible, but the implementation itself is very flexible.
- Education can be flexible in that it can be changed, but it should not be, unless you make critical mistakes.
- Warning systems are extremely flexible.
- Zone management is not flexible since decisions based on it have long-term consequences.
- Evaluation is not flexible since it depends on the "screenshots" being evaluated.
- Administrative policies and regeneration usually take longer, and their timeframes of implementation are not that short.
- Political flexibility might be even harder to consider. A lot of measures can be changed based on political alignment, but once more, they shouldn't.

INTERACTION

- Education can be tricky, but in general it has a very positive and large impact.

GENERAL

- List of measures matches real life experiences quite well.
- Quantification of Soft Measures is really the main barrier to properly implementing them.

ECONOMIC

- Education is usually cheap. Evaluation too.
- Measures that require supplementary infrastructure tend to cost more. By extension, hard measures could be considered the most expensive.
- Zone management is a one-time administrative investment, while a lot of the ongoing costs are offloaded to the end user.
- Hard measures frontload costs, regeneration backload costs. But most measures package costs into big batches.
- There is a tendency to massively invest at once after crisis events, which makes maintenance more difficult.
- Some measures are not expensive themselves but come attached to supplementary costs.

POLITICAL

- The national stance is different from the municipal stand.
- Warning systems are easy to sell. Low impact and they look smart and efficient. Evaluation can follow a similar path.
- Hard measures are not hard to sell due to their clear functioning.
- Regeneration can be very hard to pass through politics due to interests involved and economic complexity. Zone management follows the same idea.
- Administrative measures can be difficult due to the mentality of hindsight (whiff, get the axe, don't swing at the right time, get the axe too) and don't waste if not needed. A lot of administrative measures (or evaluation) just struggle since they are difficult to link to benefits or needs.

SOCIAL (Struggled a bit)

- Zone management has high social costs, either due to having to understand the new risks or due to having to adhere to new rules and regulations.
- Evacuations and hard measures can have lower social costs if they don't get used aggressively. Evacuation is “follow the signs”.
- A lot of new focus is on citizen activation, even on things like designing evacuation. So, a lot of new measures that traditionally had no input from the end user now have a lot of responsibility that has been offloaded to them.
- Zone management social costs in the long term will lower aggressively if properly implemented, since it makes the future usage of the zones already adapted to the risks and willing to deal with potential consequences.

EFFICIENCY (Tricky to answer)

- A good decision-making process does not sound sexy. But it has a massive impact on other decisions and can have extremely good consequences down the line. But it does not directly impact anyone, so the benefits are yielded through other measures.

FLEXIBILITY

- Educational measures can be very flexible when thinking about the informational aspect. Things can change fast, and information spreads like wildfire. Information campaigns should be able to keep up if needed. At the same time, education can be unflexible due to having to unlearn old lessons, which slows it down when subject to change.
- Zone management has low flexibility due to the massive capital commitments and the resistance of the stakeholders involved in potential change in the policy.
- Regeneration can be split into two things; some have high flexibility (the aftermath policies), others have little (insurance schemes).
- With every warning system, you need a support system that takes a bit more time to update and adapt.
- Evacuation is related to hard measures, which means that you cannot deviate too much from the originally designed routes (the ones that work with hard measures)

INTERACTION

- Warning systems are relatively inactive until they are activated.
- Evacuation plans follow the same idea; they are ignored until they are needed.
- Administrative has very high interaction since it directly impacts everything around how decisions are made and how information flows between organizations.
- It hurts a lot of the systems when the public is not engaged.

GENERAL

- There is some overlap between the measures. Insurance could be part of regeneration or part of zone management.
- Agreements between departments (Defensie helping with a fire) could fall between the cracks of the categories we picked.
- Information flows are key; misinformation can have just as much negative impact as no information. Additionally, information flows are usually unidirectional and need more research on how to apply effectively.

ECONOMIC

- Vertical evacuation is probably cheaper than horizontal evacuation. Horizontal evacuation requires significant investment in adjacent infrastructure capable of supporting the planned movements of people or assets.

POLITICAL

- Economic and political costs go together. Low hanging fruits are easy to pass since they don't cost much money.
- Right wing parties prefer to offload responsibility to individual citizens as they value individual responsibility, while left wing parties are in favor of a more active role from the government and more willing to make extensive use of soft adaptation measures.
- Some measures are too large to be managed or financed by a single municipality. So, for example, flood warning systems will probably be expected to enter the Rijksoverheid portfolio, making their political cost in the municipal sphere much more elevated.
- On the other hand, measures such as zone management, evacuation or small-scale educational measures are extremely likely to pass since they are seen as direct responsibility of the municipality.

SOCIAL

- Corona had a strong negative impact on people's trust of the government, irrelevant of culture or place of origin, which makes soft measures harder to implement and raises their social costs.
- Social costs are strongly dependent on current world events. Flooding protection and prevention measures have a high social cost when flooding happens across the world, but this cost drops fast if flooding happens nearby.
- People want to be warned, and they do not care about the admin (keep that backstage).
- Hard measures have low social costs unless you live nearby, otherwise it has massive social costs.
- Evacuation can be extremely tricky since it strongly depends on whether people consider it necessary. Usually they do, which makes it easy on the social aspect.

EFFICIENCY

- Horizontal evacuation competes with vertical evacuation in a sense, since people tend to not want to stay in their buildings (even if denoted as safe). This can also happen the other way around, as end-users might be reticent to abandon their homes due to a lack of trust that it will be kept safe by the government in their absence.
- Hard measures perform poorly in efficiency due to the unexpected needs for 1/100-year events. Predictions are often wrong, and updates must be made, which costs an exponential amount of money. It's very unlikely to make back every euro that is spent in hard measures due to these mistakes.

FLEXIBILITY

- Not much to say here, ranking is quite straightforward.
- Flexibility depends on political parties themselves and the performance of the measure in recent times. Bad performers will be subject to more skepticism and become less flexible.

INTERACTION

- Evacuation, warning systems and evacuation have a strong interaction between themselves.
- Hard measures interact a lot with regeneration since the protected areas dictate where you should invest more in regeneration.
- Administrative, zone management and evaluation interact with each other by being more internal parts of the governance system.

GENERAL

- Responsibility matters a lot. Each level of government aims for their portfolio policies and offloads responsibility to other parts.

ECONOMIC

- Hard measures and regeneration are the most expensive measures due to the massive investments required. Hard measures are preventive and therefore cheaper than regeneration, which is after the fact.
- Educational and zone management are in the middle of the pack due to their ongoing maintenance requirements, and they can become expensive if their scope or complexity rises.
- Administrative, evaluation and evacuation policies, together with warning systems, are cheaper due to their tendency to be one-off or heavily based on planning, which is usually cheaper.

POLITICAL

- Hard measures are easy to pass since most regulatory bodies understand they are necessary to defend urban space.
- Similarly, evaluation is seen as useful to stress-test the current approaches.
- Warning systems also do good since policymakers see the clear value of it but have some worries about privacy.
- Regeneration is tricky since getting it on the agenda is easy, but figuring out the logistics is extremely tough. It tends to fare very poorly because of this.
- Evacuation is a high interest but low priority since policymakers don't want to spend time on it. Often people will focus on it after the fact, so after the cat is out of the bag.
- Administrative follows a similar train of thought.
- Zone management is difficult due to the extensive discussions involved. Not every zone will be equal, and investments will differ per zone, creating more potential for deadlock.
- Education is expensive and benefits are not reaped instantly.

SOCIAL

- Regeneration happens in a fragile environment and has the potential to carry massive social costs if mishandled.
- Education requires active engagement with the end user.
- Evaluation carries social costs in an event-based form, so it fares in the middle.
- Hard measures engage with the end-user through taxes, which are normalized and don't carry significant problems. People see the use of taxes.
- Warning systems have minimal impact, maybe an app.
- Administrative measures carry costs if they are not used properly or do not exist. Similar thoughts on evacuation plans.
- Zone management could be problematic since it could affect the value of your assets or your ability to get specific services.

EFFICIENCY

- Dikes make hard measures efficient; the others don't help much with flood protection.
- Educational measures are probably efficient, but it does not feel so for the same reason as discussed earlier; the effects are not noticeable instantly. Additionally, the lack of it can be very negative, since it would make citizens completely dependent on the government. Educational measures assist with offloading responsibility to the end user.
- Evaluation is perhaps better than education because there is no guesswork involved. The event has happened, and lessons can be taken from it.
- Regeneration has awful efficiency since businesses are involved, extracting value out of the system. It's also poorly used by the govt (Limburg example brought up in this interview too)
- Evacuation is very efficient, plans are cheap and lives expensive, so it is a good combination.
- Administrative is probably not needed in the Netherlands. The government is already experienced with decentralization. The biggest problem is who is responsible for who.
- Warning systems go straight to the top, cheap and they save lives.

FLEXIBILITY

- Hard measures are not flexible when we look at the big-ticket items.
- Education is the most flexible, and this has the potential to be extremely dangerous if not regulated properly.
- Evacuation is not very flexible since plans take quite a bit to update or change, and they depend on other assets too.
- Regeneration is not very flexible, either.
- Similarly to education, warning systems are flexible, but you don't really want them to be changed often, or they lose value.
- Administrative policies are harder to change than zone management ones since they require significant discussions between policymakers, as opposed to updating zone mapping based on new data.

INTERACTION

- Hard measures and zone management have strong interactions with each other. The water boards focus on this in NL.
- Regeneration is a bit of an odd one out.
- The other five measures interact with each other due to being event-based and information sharing.

ECONOMIC

- It is more expensive to regenerate than to build infrastructure in advance.
- Education is 3rd in costs but much less than the first 2 (Hard and Regen)
- The bottom 5 measures are purely organizational, so they do not incur significant consistent costs.

POLITICAL

- Infrastructure and regeneration at the top once more due to expenses.
- The other 6 go together since they do not incur a lot of costs, which makes it easy for them to pass the policymaking stages.

SOCIAL

- End users want robust hard infrastructure, and they don't engage much.
- The only measures that engage the end-user aggressively are education campaigns, with some effort required for evacuation.
- The rest of the measures don't really need anything from the end user.

EFFICIENCY

- Infrastructure and education are very efficient.
- Zone management and alarm systems are also efficient, but slightly less so.
- Administrative measures are not extremely effective themselves because they just impact other measures without adding protection themselves.
- Regeneration and evaluation don't really have any efficiency, since they are completely after the fact, when damage is already done.

FLEXIBILITY

- Not many comments.

INTERACTION

- Not much to say either.

GENERAL

- In Valencia, evacuation points were non-existent because traditionally designated safe zones were suddenly not safe. Chaos arose by just telling people to “run somewhere high”.
- Evacuation on large scales in the urban sphere is IMPOSSIBLE; you need to hybridize vertical and horizontal evacuation. Plans need to account for this, or infrastructure will collapse and death risks with rise exponentially.
- Measures are pushed forward right after events.
- Some stressful events are so massive that hard infrastructure is physically incapable of preventing problems. You will need other things.
- Administrative protocols in Valencia account for emergency services in the province being incapacitated and depend on Alacant and Castelló coming in. This is flipped for Alacant or Castelló, where Valencian services would come in. In the flooding events

the services coming from outside were not allowed to enter because of Carlos Mazón. This might now be a bit extreme due to overcorrection.

- Warning systems worked poorly; information arrived late and disjointed. This was due to fear of alarmism.
- In Valencia, previous flood events have usually caused citizens to run to the garage and drive away before it arrives. This was a problem since it created a lot of trapped people who died in garages as flooding arrived almost instantly.
- In Spain, zone management is implemented but fails often due to corruption. Zone management would be a very strong solution if implemented properly.
- 8 Months to fix the 20 metro stations damaged in Valencia, regeneration is extremely expensive, it is best to prevent the damage, since it would save damage and potential deaths. In most cases help never gets there.
- Insurance often does not cover when expected. In critical events firms sometimes cannot even cover the expenses.
- Educational measures can help massively by giving a lot more leeway to other measures. They make end-users a lot more self-sustaining and able to assist with other measures.

ECONOMIC

- Policy is cheap, with limited effectiveness if you just keep it as just words.
- Zone management is cheap since it's policy.
- Evacuation is a bit pricier but still relatively cheap since it's mainly planning and admin.
- Warning systems are more expensive since they need extra power.
- Hard measures are the priciest but also the most useful.
- It's not just if the town can afford it, but what are the societal costs. External organizations will usually contribute to large projects. Therefore, the main question is not can they afford it, but "should they afford it?"

POLITICAL

- Education always ranks since politicians like educating the end user.
- Warning systems also do good since it is good to warn end-users.
- Hard measures are relatively easy to pass since they are proven to work.
- Zone management is tricky; it really depends on the strictness.
- Evacuation is something that is talked about much, but in practice lots of plans are symbolic and governments are not really prepared.
- Administrative, evaluation and regeneration are difficult to rank politically.

SOCIAL

- Only education requires real social engagement. They must be there whether they want to or not.
- A lot of other measures are government issues, and social engagement is minimal. The govt needs to understand the end-user, but the end user does not need to understand the policy/government.
- Hard measures are the highest on reducing social risk. This is followed by warning systems and evacuation plans to reduce the consequences. Zone management also applies but only really applies to new buildings. Education is overestimated for low-frequency events since no matter how educated you are, sometimes you take negative actions due to necessity (cheap houses in bad locations).

EFFICIENCY

- Education is nice, but practice is the one that helps the most. The education limited effectiveness is noticeable on house prices, which only change in the short term after the events.
- Zone management can be effective if you follow aggressive regulations. But needs usually overtake the regulations (NL needs houses so they build wherever).
- Warning systems have limited efficiency if public broadcasters are not involved.
- Hard measures are the most cost-efficient by far.
- Warning systems can help by reducing damage when water depths are low. It connects to evacuation which makes them work best together.
- A lot of measures don't do anything on their own, but they come back to harder measures.

FLEXIBILITY

- Zone management carries significant lock-in, together with administrative, since policies look at things they want to achieve, and do not really adapt or focus on risk reduction.
- Hard measures are not that inflexible; they just require expenses. Hard measures are planned with potential flexibility in mind. Perception is strongly against this one.

INTERACTION

- “Real measures” work together (evacuation, hard measures, warning systems, zone management)
- “Policy measures” work together to influence and improve the "real measures”. They mark the way in which you will use the "real measures” to reduce the flood risks.

GENERAL

- What is resilience? The project might need to make sure resilience is clearly defined to properly answer the question.
- Resilience doesn't exist in engineering; you need to switch your perspective to “acceptable risk” and cost.
- Some people erroneously think that Hard measures are not possible anymore.
- Some measures reduce the chance of negative events; others help with avoiding consequences.
- Water plazas would not be built if govts looked at their cost, which they seem to ignore for some unique reason.
- The most important question to ask is "what am I preparing for?”

# B

# Detailed breakdown of an insight log

ECONOMIC

- Economic ranking also works for the long term. A lot of the administrative tools already exist and not much needs to be fundamentally changed. It's paperwork or pure policy discussion. Flexible and easy to adapt to new needs.
- Evaluation is relatively new; oftentimes governments jump directly from action to action without having too much time to reminisce or review everything. Time is money, which makes evaluation surprisingly expensive.

**Figure B.1:** Economic insight log for interview 1.

Figure [B.1] shows the two main insights drawn from the open discussion section of the interview, concerning economic cost. The first statement answers the open question of "how are costs distributed time-wise?". The second statement is a justification for the poor rank evaluation received in this interview (7th out of 8).

POLITICAL

- Political costs do not change too much with time. Most politicians in R'dam agree on the importance of water and climate safety. It is a bit of a non-political issue when money used is not absurd.
- Politically, a lot of the measures do not need to be revisited in the political sphere. Just keep costs low.
- Regeneration is tricky due to the preferences of each party on how to do it.
- Negative views on feedback and evaluation due to political games. Evaluation tends to focus on what did not work, which does not play nicely in the politics game, where you want to focus on your wins. People don't like it much.
- Even checking out if invested money did something, is not a guarantee in the R'dam system due to their aversion to feedback.

**Figure B.2:** Political insight log for interview 1.

Figure [B.2] shows the political insights from interview 1. The first two insights provide an answer to the question of "How do political costs develop over time?" and link political costs with economic expenditure. The last three insights expand on the reasoning behind the bottom two placements of evaluation (ranked 8th out of 8) and regeneration (ranked 7th out of 8) in the political cost ranking of this interview.

SOCIAL

- Every month water and fire emergency alarm systems are tested in R'dam, and people take them very seriously.
- Nothern to Southern Europe, people in the North are a lot more willing to follow government policies or recommendations than people in the south.

**Figure B.3:** Social engagement insight log for interview 1.

Figure [B.3] provides the social engagement insights from interview 1. The first insight expands on the topic of warning systems, using a real-life example from the Netherlands to illustrate its application. The second insight addresses the unstructured question, "how does the end user impact this (referring to the social engagement of measures)?" and links the expected social engagement of adaptation measures with the cultural background of the end-user.

EFFICIENCY

- Education is not effective instantly, but consistent investment scales exponentially, even beating warning systems. People will know what to do without needing to hear it from a warning system.
- Evacuation in urban areas is not very effective because some people actively ignore the rules. Socio-economic aspects play a role in whether someone does what evacuation plans ask or instead focus on their personal preferences (families). Culture itself also plays a significant role, with cultures placing a strong emphasis on family ties showing stronger chances of disrupting evacuation orders.
- World events happening at the time of the crisis influence how likely people are to follow government directives.

**Figure B.4:** Cost-efficiency insight log for interview 1.

Figure [B.4] provides the three insights on cost-efficiency from interview 1. The expert focused on pure efficiency aspects since they believed them to be more relevant for the topic. The first one expands on educational measures, arguing that their rank (1st out of 8) does not reflect an immediate situation after implementation, and requires time to reach. The second insight expands on evacuation and justifies the poor rank (7th out of 8) on practical experiences in the city of Rotterdam, during other crisis events. The last insight discusses the relevance of current world events on general cost-efficiency, due to their ability to positively or negatively impact measure efficiency. This impact comes from the end-user's perception of the necessity of the measures.

FLEXIBILITY

- Time is also considered when discussing flexibility. So, education, for example, is at the bottom of the list because it takes a lot of time to change it, not because it cannot be done. You could change the curriculum every 6 months, but you probably shouldn't.
- Political games do not influence the flexibility picture if the topic is considered "crisis" level. In these crisis situations, the administration acts first and then justifies it to the parties. This is agreed in advance with the parties. They want the problem solved ASAP, before discussing the details.

**Figure B.5:** Flexibility & reversibility insight log for interview 1.

Figure [B.5] covers the two insights from interview 1 on flexibility & reversibility. The first one is a

clarification on the entire ranking. The expert originally tried to use the vertical space to indicate time, similar to the example explained in figure [6.7], but decided to simplify out of convenience and limit it purely to placing educational measures last. The second insight is a natural expansion on how usual practices reducing soft adaptation flexibility could be bypassed in critical situations.

INTERACTION

- Warning systems will help citizens evacuate to the areas made safe by hard measures and away from those seen as risky through zone management, for example. These measures interact with each other a lot.
- Evaluation is important but has no real interaction when actions are very time sensitive.

**Figure B.6:** Interaction insight log for interview 1.

Figure [B.6] shows the two insights drawn from interview 1 on the topic of measure interaction. The first insight expands on the co-benefits created through the interaction of hard, evacuation, warning systems and zone management measures. The second insight focuses on evaluation and the peculiarities of its interaction, which only happens outside of crisis situations.

GENERAL

- Governance structure is important. Decentralization in the R'dam government is worthy of study. When decentralized, communication is extremely important, which makes administrative measures more important. (Who are you to tell me what to do?). The best way is to structure authority for crisis events.

**Figure B.7:** General insight log for interview 1.

Figure [B.7] shows the insight that could not be included into any of the previous six categories, and was therefore placed in then general section. It provides an additional line of research on the topic of decentralization in the Rotterdam government, which leads to issues of departments reacting negatively to perceived authority breaches. It also expands on the utility of administrative measures, which are considered to include governance and responsibility protocols for crisis events.

# C

# Blank Informed Consent Form Template

Dear

You are being invited to participate in a research study titled Flood Resilience through Soft-Adaptation Measures. This study is being done by Samuel Isaac Colijn Llinares, from the TU Delft.

The purpose of this research interview is to gather some information on soft-adaptation measures applied to increase flood resilience in the urban environment. The interview will take maximum 60 minutes to complete. The data extracted from the interview will be used as the basis to discuss the benefits and costs of implementing soft-adaptation measures; knowledge on their interactions will also be obtained. You will be asked to answer a series of open-ended questions covering your thoughts and experiences working with soft-adaptation measures during extreme flooding events. Questions covering your experiences and thoughts when working without them will also be included.

As with any research activity with personal information, the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by limiting personal data gathering to the minimum (name, email, country and relevant position). Additionally, this personal identifiable data will be kept in a separate storage within the TU Delft OneDrive, further compartmentalizing it from regular project data. Additionally, only information approved by you will be in the final thesis report. This thesis will be published in a public database and freely accessible.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. As mentioned, after the interview is over, you will be provided with a written transcript that you may revise and approve if satisfied. Only the approved transcript will be used further during the thesis. The transcript will NOT be included in the public thesis and will be destroyed after the research is complete. You may change your approval, and request changes up to 4 weeks prior to the end date of the project (Project is expected to be complete by mid-August).

You are urged to read and complete the questions in the following pages, and you may contact the responsible researcher at the following email address: scolijnllinare@tudelft.nl

| PLEASE TICK THE APPROPRIATE BOXES | Yes | No |
|---|---|---|
| **A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION** | | |
| I have read and understood the study information dated , or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. | ☐ | ☐ |
| I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason. | ☐ | ☐ |
| I understand that taking part in the study involves:<br>• Participating in a 1 to 1 interview where I will be expected to answer questions. These will be regarding my opinions and experiences working with adaptation measures catalogued as soft.<br>• Receiving the questions in advance and being permitted to skip those I do not wish to answer.<br>• The interview being audio-recorded, providing an MP3 file.<br>• The transcription of the audio-recording using specialized software. The transcript will be anonymous, and I will get to review and approve it prior to it being utilized in the research.<br>• That the anonymous transcripts will be shared with the thesis committee and supervisors, to discuss and generalize information into specific insights.<br>• The insights extracted from the transcripts will be used in the discussion part of the thesis.<br>• The audio files and the transcripts will be deleted as soon as they are no longer necessary. | ☐ | ☐ |
| I understand that I will not be compensated for my participation | ☐ | ☐ |
| I understand that the study will end in July 2025 | ☐ | ☐ |
| **B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)** | | |
| I understand that taking part in the study is fully voluntary and I may either skip individual questions or withdraw from the research at any point. | ☐ | ☐ |
| I understand that taking part in the study also involves collecting specific personally | ☐ | ☐ |

| | | |
|---|---|---|
| identifiable information (PII) and associated personally identifiable research data (PIRD) with the potential risk of my identity being revealed and my professional reputation being damaged.<br>• Name<br>• Email<br>• Country of work<br>• Professional Field of work and/or experience on the field. | | |
| I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach:<br>• I will get to review and approve any data that I contributed to.<br>• Data will be anonymized as soon as possible.<br>• Any data containing personal identifiable information will be kept in separate drives from the rest of the project data, with access restricted to just the main researcher. | ☐ | ☐ |
| I understand that personal information collected about me that can identify me, such as my name, will not be shared. | ☐ | ☐ |
| I understand that the (identifiable) personal data I provide will be destroyed.<br>• Audio files after a transcript has been made by the software.<br>• Unapproved transcripts after final approval or withdrawal from the study.<br>• Approved anonymous transcripts after conclusion of the research. | ☐ | ☐ |
| **C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION** | | |
| I understand that after the research study the de-identified information, I provide will be used to discuss the potential costs and benefits of soft adaptation measures on flood resilience. This may not be limited to this research project but to any subsequent projects that cite this one as a source. | ☐ | ☐ |
| I agree that my responses, views or other input can be quoted anonymously in research outputs for this thesis. | ☐ | ☐ |
| **D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE** | | |
| I give permission for the anonymized insights obtained from my approved transcripts to be archived in the TU Delft thesis repository, so it can be used for future research | ☐ | ☐ |

| | | |
|---|---|---|
| and learning. | | |
| I give permission for the anonymized responses, views or other inputs obtained from my approved transcripts to be archived in the TU Delft thesis repository, so it can be used for future research and learning. | ☐ | ☐ |
| I understand that access to this repository is open. | ☐ | ☐ |

**Signatures**

_____ _____ _____

Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Samuel Colijn _____ _____

Samuel Colijn Signature Date

Study contacts details for further information: Samuel Colijn scolijnllinare@tudelft.nl

# D

# Internal preliminary statistics

With such a small sample size, it is immediately apparent that any statistics performed on the ordinal data sets have no statistical significance. The utilization of statistics, therefore, carries no authority in the final results. They are utilized purely as a supplementary tool aimed to streamline the subsequent qualitative analysis, which dictates the final results of the measure analysis.

Statistical descriptors are used purely for consistency and represent a personal choice on the part of the researcher. Utilizing statistical descriptors for the MCDA ensures that every measure is initially described in the same way and aims to reduce any additional bias before the qualitative analysis.

**Ordinal data**
The choice of output from the data-gathering stage is in the form of rankings. This type of result is formally referred to as ordinal data, a statistical data type where the variables' ordered categories and the distances between categories are not known (Agresti 2013). Likert scales are an extremely common example of question formats that output ordinal data. The type of format that outputs this data is said to reside in the ordinal scale, a term originally coined by psychologist S.S.Stevens in their 1946 paper discussing the levels of measurements that statistical data could fit into (Stevens 1946). Data in the ordinal scale is defined by two things:

1. It has an explicit ranking between potential answers, meaning that every potential answer has a relationship with the others, by reason of being ranked "higher than" or "lower than".
2. The intervals between the ranks are unknown, meaning that it cannot be inferred if the interval between the first rank and the second one is equal to the interval between the second and the third rank.

The second defining aspect of ordinal data appears like a relatively minor distinction that has significant implications when considering statistical calculations on the data. The two of immediate relevance to the research methodology involve the central tendency and the statistical dispersion of the dataset. They are covered individually in their respective methodology parts.

Despite the statistical challenges, the utilization of ordinal data presents very strong utility for this research due to the ease of gathering, as values just need to be compared to one another relatively, with no distinction over an absolute scale.

**Incomplete datasets**
Some experts decided to exclude measures from their ranking, changing the ordinal scale from 8 to 1 down to 6 to 1. This becomes problematic when performing statistical operations since it can have a significant impact by skewing the data. Therefore, every ranking has been converted into a relative percentile, effectively normalizing everything into the same scale.

**Central tendency**
In statistics, the central tendency is defined as the typical value for a probability distribution (Weisberg 1992). This is commonly referred to as the "average" of the distribution. There are plenty of ways to describe the central tendency of a distribution, with the most typical ones being the arithmetic mean, the median, and the mode.

When concerning ordinal data, it is agreed within the field of statistics that the commonly used arithmetic mean is not acceptable from a mathematical perspective for defining the central tendency of the distribution and that the median or mode should be employed instead (Blaikie 2003)(Jamieson 2004). The reason this is fairly complex and out of the scope of this research, but it relates to the underlying assumptions that come attached to the arithmetic mean that do not apply to ordinal data.

The formal definition of the median is set as the value in a data sample that separates the lower half from the upper half. It is also known as the 50th percentile or 2nd quartile since these values represent the exact same concept (Hogg and Craig 1995). The calculation of the median is mathematically trivial, but for clarity to the potential reader, it is included in equation [D.1], sourced from (Hogg and Craig 1995).

$$\tilde{x} = \begin{cases} x_{(n+1)/2}, & \text{if } n \text{ is odd} \\ \frac{x_{n/2} + x_{(n/2)+1}}{2}, & \text{if } n \text{ is even} \end{cases} \tag{D.1}$$

For this research, the median is of utility since it allows the ranking datasets gathered from the interviews and shown in section [6.3.2] to be compressed into a single representative number each. As previously explained, the median ranking of a measure in a category (criterion in the MCDA) is the preliminary score it receives for it.

**Statistical dispersion**
There is an additional indicator included in the unweighted scoring matrix, aimed at contextualizing the scores every measure received for each criterion. This indicator is directly related to the statistical dispersion shown by the dataset.

The concept of statistical dispersion refers to the extent to which a distribution is clustered or scattered (NIST n.d.). There is no formal definition for dispersion within statistics, and most of the focus lies on the different approaches to measure it instead. Some examples include the standard deviation, the interquartile Range, and the mean absolute deviation.

Similarly to the central tendency, many dispersion descriptors commonly used in statistical analysis, such as the standard deviation, are not considered acceptable when describing ordinal datasets (Stevens 1946). The only dispersion descriptors considered acceptable for ordinal data are the ones that relate purely to positional dispersion, without making any assumptions on the underlying data (Stevens 1946). The interquartile range (IQR) is such an example, and it is the one used to describe statistical dispersion in this research.

The formal definition of the IQR is the difference between the 75th and the 25th percentiles of the data, as shown in equation [D.2], from (Dekking et al. 2005):

$$IQR = Q_3 - Q_1 \tag{D.2}$$

To further clarify, it can be helpful to consider the two halves split by the median (which is also the 50th percentile). If the median of each of these halves is subsequently calculated, the IQR becomes the

difference between them. As a logical deduction, a large IQR shows a dataset with very significant scattering (high dispersion), while a small IQR shows a dataset with significant clustering (low dispersion).

The dispersion is incorporated into the unweighted scoring matrix through a confidence parameter adjacent to the score each option receives in the criterion. This parameter provides an immediate descriptor of how clustered or scattered the expert opinions were, effectively displaying how representative the central tendency score is.

| Confidence Symbol | Meaning | IQR |
|---|---|---|
| + [PLUS] | The rankings were clustered around one or two ranks | & < 20 |
| [None] | The rankings were clustered around an area of the scale | 20 < & < 40 |
| - [MINUS] | The rankings were all over the scale | 40 < & |

**Table D.1:** The symbols for the confidence parameter, with descriptions and IQR correlation. .

# D.1. Preliminary statistical descriptors

The following section encompasses all the preliminary results from the additional preparation performed on the data gathered from Chapter 6. This data represents one of the building blocks for the final results of this chapter, covered in the following pages, in section [7.3].

The first half concerns the results for the statistical descriptors of each ranking dataset. The preliminary MCDA scoring matrix is built from these descriptors and is shown at the end of the section. While preliminary, it is relevant since the subsequent qualitative analysis will utilize it as the base.

### Economic cost

Table [D.2] shows the medians and IQRs for every measure in the economic cost category. As explained in the methodology, the rankings have been converted into absolute rankings, so measures ranked last (most expensive) are defined as the 100th percentile of ranks, measures ranked first (cheapest) are defined as the 1st percentile of ranks, etc. This is regardless of the actual numerical ranking they received in the data.

| ECONOMIC COST | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| Median | 93 | 57 | 21,5 | 64 | 14,5 | 57 | 29 | 78,5 |
| IQR | 14 | 3,5 | 60,75 | 35,25 | 29 | 49,5 | 32,5 | 60,5 |

**Table D.2:** Median and Interquartile range (IQR) for every measure on the criteria of economic cost.

It can be seen that Hard Measures and Zone management had very little dispersion. On the other hand, regeneration, warning systems, and evaluation had significant dispersion.

### Political cost

Table [D.3] shows the statistical descriptors for political cost. Similarly to economic cost, measures were placed in the 100th percentile if ranked last by the experts (least likely to pass through legislative bodies) and in the 1st percentile if they were ranked first (most likely to pass). If ranked in the middle, they were placed on the respective percentile, varying depending on the absolute number of measures ranked.

| POLITICAL COST | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| Median | 55 | 66 | 36 | 43 | 57 | 27 | 14,5 | 100 |
| IQR | 49,5 | 43 | 59,75 | 15,5 | 32,25 | 29 | 50 | 10,5 |

**Table D.3:** Median and Interquartile range (IQR) for every measure on the criteria of political cost.

From table [D.3], it can be seen that regeneration and evacuation showed the least dispersion, while hard, evacuation, educational, and zone management measures displayed significant dispersion of ranks given by the experts.

### Social engagement

Social engagement is represented by the necessity to engage the end-users to properly implement adaptation measures. Measures that were ranked in the lower percentiles represent those requiring less engagement of the end-user, while the ones ranked in the higher percentiles require more engagement of the end-user. Table [D.4] provides the results for social engagement.

| SOCIAL COST | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| Median | 14 | 43 | 57 | 71 | 14 | 29 | 100 | 71 |
| IQR | 50 | 35,5 | 14 | 64,5 | 43 | 43 | 17,75 | 28 |

**Table D.4:** Median and Interquartile range (IQR) for every measure on the criteria of social engagement.

From table [D.4], it can be immediately noticed that evaluation and educational measures display low dispersion. It can also be immediately seen that education requires the most engagement of the end-user to implement, performing poorly in the category. Warning systems, evacuation, administrative, and hard measures present high dispersion in their results. Hard and administrative measures also show the lowest percentiles of central tendency, meaning that they are deemed by the experts to incur the lowest engagement of the end-user.

### Cost-effectiveness

Cost-effectiveness concerns the ratio between the investment required for a measure and the benefits it provides in increasing flood resilience. Measures in the lower percentiles of the data are deemed to be more "cost-efficient" and, by extension, a better investment when capital is limited. Measures in the higher percentiles are deemed to be less so and best skipped as an option if resources are limited. The descriptors for cost-effectiveness are placed in table [D.5].

| COST-EFFECTIVENESS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| Median | 43 | 50 | 78,5 | 21,5 | 64 | 36 | 28,5 | 93 |
| IQR | 38,75 | 31,5 | 53,75 | 39,5 | 45,75 | 32,5 | 43 | 17,75 |

**Table D.5:** Median and Interquartile range (IQR) for every measure on the criteria of cost-effectiveness.

The most immediate aspect of cost-effectiveness is the extremely poor performance of regeneration measures when compared to the other. This is exacerbated by the low dispersion, showing that most experts consistently ranked it in the last categories. Dispersion is quite elevated in this criterion, reflecting the disagreements experts had with each other.

### Flexibility and reversibility

Flexibility (& reversibility) is the last criterion of the MCDA, and it reflects the difficulty of modifying or adapting the measure to changes in the environment. Measures in the high percentiles were ranked lower and are difficult to modify and adapt after they have been deployed. On the other hand, measures in the low percentiles were ranked higher and are easier to change after deployment. Table [D.6] shows the statistical descriptors.

| FLEXIBILITY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Hard Measure | Zone Manage | Evaluation | Evacuation | Administrative | Warning | Educational | Regeneration |
| Median | 100 | 71,5 | 7 | 50 | 43 | 21,5 | 14 | 64 |
| IQR | 17,75 | 32,5 | 39,5 | 72 | 17,5 | 22 | 39,5 | 28,25 |

**Table D.6:** Median and Interquartile range (IQR) for every measure on the criteria of flexibility.

The most immediate aspect of flexibility is the low performance of hard adaptation measures, which also shows little dispersion. Zone Management and Regeneration score a bit better, but they show a bit more dispersion. Evacuation and administrative sit in the center spots, the former with significant dispersion and the latter with much less. Evaluation, education, and warning systems are the best three scoring measures, with all three showing some dispersion.

**Preliminary MCDA scoring matrix**

Figure [D.7] shows the preliminary unweighted scoring matrix of the MCDA. It can be noticed that the information in the scoring matrix originates directly from the results of the statistical part criteria.

The main difference is the utilization of the confidence symbol next to the scoring of each measure on every criterion. The symbol is directly related to the dispersion (described by the IQR). The exact meaning of the confidence symbol is described in Table [D.1], earlier in this chapter.

| | ECONOMIC COST | POLITICAL COST | SOCIAL COST | COST-EFFECTIVENESS | FLEXIBILITY |
|---|---|---|---|---|---|
| Hard Measures | 93 (+) | 55 (-) | 14 (-) | 43 | 100 (+) |
| Zone Mgmt. | 57 (+) | 66 (-) | 43 | 50 | 71,5 |
| Evaluation | 21,5 (-) | 36 (-) | 57 (+) | 78,5 (-) | 7 |
| Evacuation | 64 | 43 (+) | 71 (-) | 21,5 | 50 (+) |
| Administrative | 14,5 | 57 | 14 (-) | 64 (-) | 43 (-) |
| Warning | 57 (-) | 27 | 29 (-) | 36 | 21,5 |
| Educational | 29 | 14,5 (-) | 100 (+) | 28,5 (-) | 14 |
| Regeneration | 78,5 (-) | 100 (+) | 71 | 93 (+) | 64 |

**Table D.7:** Preliminary scoring matrix for the MCDA, with the confidence parameter added to the right of the data

From Table [D.7], it can be seen that all soft adaptation measures perform better than the hard measure in the economic cost category. The specific order from worst to best within the soft adaptation measures is regeneration, followed by evacuation, zone management and warning systems, which scored the same, followed by educational, evaluation, and lastly, administrative measures, which scored the best.

Political cost is more mixed, with three soft adaptation measures scoring worse than the hard measure, and the other four scoring better. The soft adaptation measures in the former group include regeneration, zone management, and administrative measures, in that order from worst to best, but still score worse than hard measures. The ones in the latter group include evacuation, evaluation, warning systems, and educational measures, which all scored better than hard measures, also in that order.

In the social cost criterion, all soft measures scored worse than hard measures, except for administrative measures, which tied in the best spot. The specific order encompasses warning systems and zone management, followed by evaluation, evacuation, and regeneration, which are also tied, and education as a clear worst performer in the social cost criterion.

Cost-effectiveness provides another mixed result, with three soft adaptation measures performing better than the hard measures. These are, from best to worst: evacuation measures, educational measures, and warning systems. The other four soft adaptation measures perform worse than the hard adaptation measures. They are, from relatively best to worst: zone management, administrative, evaluation, and regeneration.

Lastly, every soft adaptation measure performs better than hard measures in the flexibility & reversibility criterion. They are, from best to worst: evaluation, educational, warning systems, administrative, evacuation, regeneration, and zone management.