University of Reading

Being prepared for an uncertain future with no-regrets: building on lessons learnt from the flooding event in Germany in 2021

PhD in Environmental Science

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Joy Ommer

Abstract

We are living under deep uncertainty about whether we will experience a hazard one day in the future or not. Nowadays, also climate change and its entailing extreme weather is adding relevance and urgency to disaster preparedness. Yet, it is easy to post-pone the decision on potential preparedness actions for a hazard (which might never happen). But how long do we post-pone this decision?

This thesis aimed to identify ways to encourage citizens to prepare for a future where the occurrence of hazards is deeply uncertain. To achieve this aim, this thesis 1) investigated barriers to individual disaster preparedness through a survey with citizens affected by the floods in Germany in 2021; 2) developed a no-regrets framework for citizens' preparedness under uncertainty and one framework to pre-assess potential side effects of no-regrets actions (specifically Nature-based Solutions), and 3) explored practical examples for facilitating the uptake of no-regrets preparedness actions.

The survey highlighted, firstly, the importance of the ability to imagine hazard scenarios for individual disaster preparedness; secondly, the need to bridge the interface between citizens and local authorities towards collective risk governance, and thirdly, that the main regrets of citizens on disaster preparedness are about their inaction. This thesis suggests the adoption of the no-regrets approach to guide citizens in their disaster preparedness further considering the uncertainty of the future. In this regard, the need is raised to focus on long-term preparedness which basically starts today. Moreover, the thesis acknowledges that the uptake of a disaster preparedness behaviour by citizens needs to be facilitated which further includes motivation. In support of this, different ways to promote a disaster preparedness behaviour are presented including collective action, knowledge bridging, and motivational approaches such as games. Overall, the facilitation needs to primarily focus on citizens without previous hazard experience or risk awareness.

Acknowledgements

After writing more than 60 000 words, I come to this section and feel out of words. Tears starting to form in my eyes and to prevent the flooding of my keyboard, I will be brief and would like to thank everyone who has directly and indirectly supported me during this journey!

With special thanks to:

My supervisors who have supported me and my ideas and have guided my journey to great directions: Hannah Cloke, Milan Kalas, Jess Neumann, and Sophie Blackburn

My partner who has always taken care of my well-being by reminding me to take breaks and has been there for me during all phases: Pekka Veiste

My great great aunt who always encouraged and supported me: Hanni Bald

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List of Acronyms

FRG	Flood risk governance
FRM	Flood risk management
NBS	Nature-based Solutions
PhD	Doctor of Philosophy

My PhD Journey

My PhD journey may have started in my last week of my Traineeship at the Joint Research Centre of the European Commission when I went upstairs to refill my water bottle and bumped into the chat of my Trainee supervisor and a friend of him (Milan). After talking for 5 min, Milan offered me a job.

That's how I started working for KAJO s.r.o. in 2019. KAJO is a very small company and every of my colleagues lived in a different country. Therefore, it was agreed, at some point, that I can work from Finland for the company. After not having lived in one place longer than a year for many years, this might have been the start for me to settle - at least a bit.

Figure 1: My KAJO colleagues and me

Working at KAJO became a great chance in many ways. Foremost, I really like my work as it is very versatile and always at the edge of research and science communication through tools, games, etc. Milan has been always super supportive in my development and especially of my new ideas. Working in various EU-funded projects, I could establish a great network around Europe and beyond. But also, the projects itself had a great influence on my PhD (which I will explain in more detail later on).

Soon after joining KAJO, Milan offered me to do a PhD suggesting a few friends who might be great PhD supervisors, and this is how I contacted Hannah asking whether she would be interested in being my supervisor. After the official application, I started my PhD in 2020 during the high season of Covid-19. In my case, Covid-19 was actually beneficial for me because I decided to do my PhD by distance (to not move again) and all courses and informal coffee meetings were happening online; thus, I was able to join these.

I started my PhD with a clear plan and structure of articles and topics I wanted to explore during these 3-4 years. At the time of application, I was working in one project called OPERANDUM which focused on Nature-based Solutions for disaster risk reduction. The plan was to develop a decision-support tool for Nature-based Solutions

as part of my PhD. As mentioned before, I had a clear plan and have been working on it. In the end, I developed a good prototype of the tool (with support of my colleagues of course) but by that time the tool was not the main topic of my PhD anymore. What happened were the floods in western Europe in July 2021. As flooding occurred in my hometown (close to Cologne) and everywhere in this region (while I was cycling in Finland during the heatwave which (partly) caused the low pressure to stagnate over western Europe). This flooding event affected my friends and family to different extends and I heard a lot of different vibes regarding the management of the disaster, etc. This was the reason why I started a survey in affected areas to learn more about the perspective of the citizens on this event and to give them a voice. Milan, Hannah, and Jess supported my idea of conducting this survey and said that we would find a way how to integrate it into my clear plan.

In the end, my plan was turned around completely as now the challenge was how can I fit the toolkit for Nature-based Solutions into my study on the floods in Germany. By looking at Nature-based Solutions from a no-regrets perspective, the no-regrets approach became my overall glue.

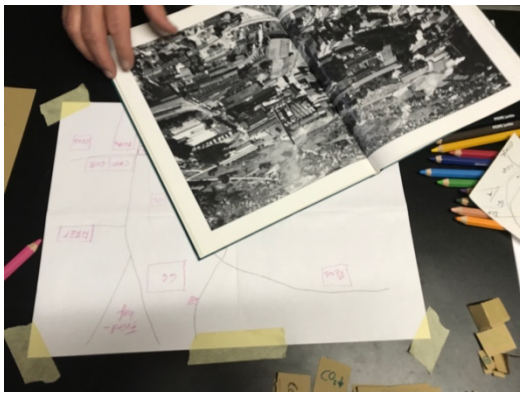

Figure 2: Testing the I-CHANGE game with my father while learning more about the history of the area

Throughout the years, we won more projects which influenced my PhD journey indirectly. The I-CHANGE project was probably the most influential one as I started more looking into citizen engagement and behavioural change. As the technical partner of the project, we are responsible to create a dashboard for low-cost sensor data, a serious game (Our Climate Story), and an app (ChallengeYeti). To make these most impactful, we have been working on bridging the scientific outputs of the project to citizens (who are the main target group). Writing a project proposal (CYGNUS) for high impact low probability events led me to delve deeper into no-regrets actions. Within the TRIGGER project, we have been investigating the health impacts of climate stressors. As part of our work, we used an innovative text mining approach to analyse policies on their integration of health impacts and social media posts to gain a better understanding on the perceptions of citizens on heatwaves. This work showed that mental health impacts are not sufficiently acknowledged and

discusses which closely relates to one of the main findings of my PhD. My project journey continues with new ideas and inputs in context with the movement Early Warning 4 All (MEDEWSA project), Nature-based Solutions in Africa (ALBATROSS project), and building resilience to disasters (RETIME project), but realising that I cannot merge everything into my PhD, this journey is unfortunately ending.

Of course, it has been a time struggle sometimes to merge my full-time work with my full-time PhD and with my valuable free time, especially, after my PhD topic was not anymore directly linked to the projects I have been working on. But I don't regret it because working at the same time has taught me so many things which I probably would not have learned only pursuing the PhD.

Every time someone asks me whether I like doing my PhD, I am responding very positively, and people seem surprised about the positiveness. I have such great supervisors who made this journey very exciting, and I could learn a lot from them which I am very grateful for! Let's see where the next journey will take me...

Figure 3: Probably the one and only picture with (most of) my supervisors

1 Introduction

This is a force of nature – can we only react?
by Joy Ommer, 2024*

Long rain the days before
Almost saturated the ground
A forecast of 200ml became sound
When the water knocked at the door

It was unimaginable before
The water, in its volume
It arrived the day of doom
When the sofa became our shore

What were we supposed to do
Couldn't proact
Only react
We simply had no clue

We were powerless
We acted intuitively
Called for help vehemently
Can this experience empower us

The emergency system failed
Our expectations vanished
Our trust diminished
While the bureaucracy prevailed

Looking back
We regret

What if we had prepared
But the lack of time wasn't fair

This flooding uncertainty
Had lowered the urgency

Now, we'd anticipate the emergency

We'd be aware
We'd prepare
We'd take warnings seriously
We'd evacuate early
We'd planned it out
We'd helped others, no doubt

We wouldn't regret

** This poem was written by me, inspired by survey responses collected within this thesis.*

1.1 Motivation & Aim

Experiencing a hazard such as flooding, we start thinking about what we could have done differently and how we can prepare (better) for a potential future flood. This proactive thinking is not always present, especially if we have not experienced a hazard before. If we haven't experienced a hazard before, it may appear as an abstract event and it is under deep uncertainty. Therefore, we might just push the thought away (if it comes) or prioritise other things. Living in a developed country like Germany, we might even believe that the emergency system is perfect, and it will protect us from everything. Until it does not: the unexpected happens and we are sitting on our roof and waiting for rescue. The uncertainty around the occurrence and impact of hazards is one challenge that increases further considering climate change, potential cascading hazards, or the occurrence of hazards we have never even thought about.

The floods in Germany in July 2021 have demonstrated once again that disaster management needs to shift towards more proactive risk management. This specific flooding event was noted as one of the worst flooding events in German history because it caused the death of more than 180 people in Germany (Dietze et al., 2022). One of the main factors was that citizens were not prepared nor warned in time and overall, they have been highly dependent on the responsive disaster management system (Fekete & Sandholz, 2021). Citizens were surprised by the unexpected water intruding in their homes and most of them could only react - taking quick decisions and actions which in some cases led to death, in situations such as going to the flooded basement to save valuable items (Thieken et al., 2022).

Is (long-term) disaster preparedness by citizens an illusion? The Sendai Framework is a globally recognised framework for disaster risk management (UNISDR, 2015). This framework communicates the need for proactive disaster risk management to save lives, reduce economic loss and damages to critical infrastructure and service disruption. In particular, it acknowledges the following dimensions of risk: the hazard(s) characteristics, exposure, and vulnerability to it/them as well as our capacity to cope with it/them. With the spirit of the Sendai Framework (and its forerunners), a shift was introduced to enable being in control of a situation rather than responding to it. This shift sets a focus on reducing vulnerabilities by enhancing

capacities for disaster preparedness and response because for an emergency situation, it is vital to be able to cope with it (UNDRR, 2017). However, looking at citizens' preparedness[1], there are many hurdles in the way of taking action before a potential disaster (Kuhlicke, Seebauer, et al., 2020). For instance, uncertainty is known to be a significant barrier to preparedness (Marchau et al., 2019). Uncertainty over whether we will ever be affected by a hazard such as flooding raises the question of: should we prepare, or not? Would we regret having taken actions if a flood never occurred? When receiving a flood warning, this uncertainty is reduced but still it may not make everyone prepare.

Do we only prepare after a hazard occurred? It often happens to be that experiencing a hazard motivates us to prepare for potential future hazards (Nicklin et al., 2019). In fact, a large amount of literature is focusing on the motivation and learning effects from experiencing a hazard (Kuang & Liao, 2020). However, there are also citizens who have not experienced a (specific) hazard yet and therefore, past experiences do not function as a motivational factor. Moreover, climate change is bringing new hazards and intensities, new vulnerabilities, and foremost, new uncertainties. This means that even if we have experienced a hazard before, we may still have to anticipate the never-before-experienced. Disaster preparedness remains a challenge because of the uncertainty around hazards and climate change (UNDRR, 2022), or because we may not be aware of any risks in our area or perceive it as so low that preparedness seems not necessary (de Guttry & Ratter, 2022), we may not be able to imagine it (Kuhlicke, 2010), we may not feel capable of preparing for these natural forces (Kievik & Gutteling, 2011), or we do not see it as our own responsibility (Nikkanen et al., 2023; Snel et al., 2021).

Aim of this thesis *Identify ways that encourage citizens to prepare for a future where the occurrence of hazards is uncertain.*

[1] Note: Throughout the entire thesis, I overemphasise the individual agency. Therefore, I want to mention at this point that I do acknowledge that individual disaster preparedness is not only driven by individual's agency, but instead it can be influenced by various factors such as structural (e.g. political, economic, cultural, social) forces or limitations, lack of awareness, individual's imagination. Furthermore, I acknowledge that disaster preparedness is not a solely individual responsibility nor do I intent to blame individuals for not taking preparedness actions. However, as part of this thesis, I will not explore this in depth and therefore, an overemphasis on individual agency may be apparent.

What can we learn from a single event? Disastrous events such as the flooding in western Europe in July 2021 can be a starting point for reflection, learning, and improving. For instance, historic floods in Germany such as the Elbe flood in 2002 or the flooding of the Danube and Elbe in 2013 can be considered very influential for Germany flood risk management. These flooding events led to new laws such as the Omnibus Flood Control Act (2005) and the second Act in 2017/18 (Surminski et al., 2020). In addition, after the flooding event in 2013, a National Flood Protection Programme was funded and building resilience certificates were developed (LAWA, 2023). Even though these flooding events occurred at local or state level, their lessons learnt were used to improve flood risk management within the entire country. Simultaneously, at individual level, flood affected households tended to show higher flood awareness and willingness to take responsibility for implementing flood protection measures after these events, compared to non-flood affected households (Platt et al., 2020). Yet, learnings from any particular case study are inherently sensitive to place-specific cultures, political views, education levels, personal/individual characteristics of participants, and more. Therefore, there are always tensions in making generalisations. The empirical part of this thesis applies a case study approach but focuses on a larger area covering two German federal states. The case study area includes diverse geographical contexts (e.g., urban, rural, hilly terrain, etc.) and different socio-economic, demographic, and environmental conditions. In this regard, selecting a larger case study area can enhance the ability to identify emerging cross-cutting themes covering different sub-areas which may not be visible when focusing only on one sub-area. Hence, the findings can be more applicable within the case study area but also can lead to more robust theoretical insights. Hence, this thesis aims to explore emerging factors influencing flood (un)preparedness across the case study area to derive the core of learnings which have relevance beyond spatial borders and personalities.

1.2 Research objective & questions

This thesis is compiled as a collection of articles and the overall aim of the thesis is supported by three objectives and research questions which are introduced in the following.

1.2.1 Disaster preparedness lessons from the floods in Germany in 2021

The German floods became an example for the need of enhancing individual disaster preparedness because many citizens were not prepared and hence, surprised by the unexpected event. Overall, the event reminded us of the need to be always prepared for hazards as they may happen unexpectedly (due to different reasons). As citizens disaster preparedness motivation is dependent on many influencing factors, the first part of this thesis will aim to distil lessons learnt from the floods in Germany in 2021 to extend the scientific knowledge on disaster preparedness.

Research Question I What can we learn from the flooding experiences of citizens to improve citizens' disaster preparedness for the future?

Objective I Explore factors that shaped individual disaster preparedness action and inaction in Germany in 2021.

Key contributions

- Emphasising imagination as a key determinant for risk perception and hence, for disaster preparedness motivation by citizens (Chapter 4).
- Situating perceived self-responsibility by citizens within legal-institutional structures in Germany (Chapter 5).
- Advancing knowledge on regret of disaster preparedness decision-making (Chapter 6).

1.2.2 Towards citizens' disaster preparedness under uncertainty with no-regrets

One great challenge to decision-making on disaster preparedness is uncertainty – the uncertainty of whether we will be affected by a hazard, the uncertainty of its magnitude, or the uncertainty of its impact. Yet, uncertainty is not a new challenge in general as it was explored in many research discourses. One approach to take decisions under uncertainty is the no-regrets approach which aims to minimise regrets throughout all scenarios rather than seeking the most optimal solution for one scenario. This approach was adopted in climate sciences to overcome the hurdles of uncertainty in climate change mitigation policy design. The no-regrets approach could further be used to guide citizens' disaster preparedness under uncertainty, but this has not been explored yet.

Research Question II How can uncertainty be circumvented to encourage citizens to prepare for disasters without regretting their actions?

Objective II Understand how and to what extent the no-regrets approach can be adopted to guide citizens towards disaster preparedness under uncertainty.

Key contributions

- Extending the no-regrets scholarship by developing a framework for individual and collective actions for disaster preparedness under uncertainty (Chapter 7).
- Enhancing evidence-based and no-regrets decision-making on Nature-based Solution through the quantification of their co-benefits (Chapter 8).

1.2.3 Facilitating the uptake of no-regrets actions

Even if no-regrets actions are acknowledged in science and their characteristics can be motivative, it does not mean that these actions are taken up by citizens. Therefore, the uptake of no-regrets actions needs to be facilitated (e.g., by neighbours, technology, local authorities, or other). Especially, when citizens have not experienced a specific hazard before, they may lack motivation but also knowledge and capabilities to take preparedness actions. In other words, greater attention on the science-practice interface is needed to facilitate citizens' disaster preparedness under uncertainty with no-regrets.

Research Question III How can citizens' disaster preparedness under uncertainty with no-regrets be facilitated in practice?

Objective III Identification of methods and tools to facilitate the uptake of no-regrets actions for disaster preparedness by citizens in practice.

Key contributions

- Bridging scientific outputs into practice to enhance the adoption of no-regrets thinking and the uptake of a disaster preparedness behaviour (Chapter 9).

1.3 Thesis outline

In regard to the overall aim of this thesis to *identify ways that encourage citizens to prepare for a future where the occurrence of hazards is deeply uncertain*, this thesis is structured around the three research questions introduced in Section 1.2. Summarising these and the structure of this thesis is presented as follows in Figure 4.

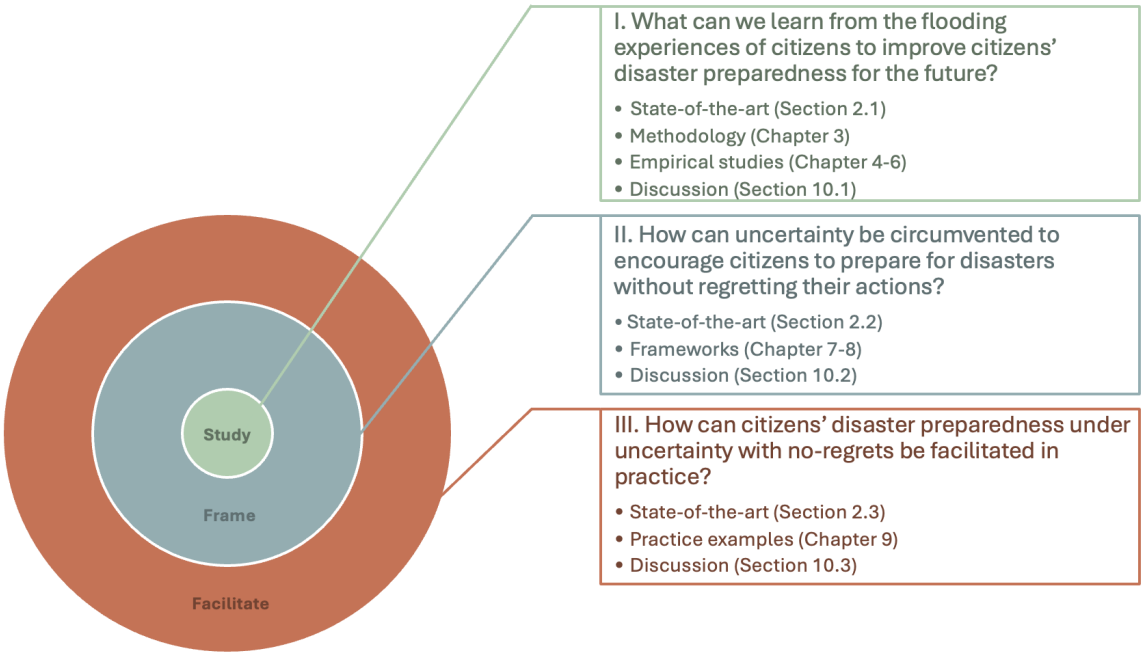

Figure 4: Thesis structure

2 Disaster preparedness under uncertainty

When a sudden onset disaster such as flooding approaches, we[2] (as the general public) can be trapped in a situation where we have to take quick decisions. In these situations, we are more commonly drawing on our intuition; thus, we act using mental short cuts and a trial-and-error decision-making (Nalau et al., 2021). However, research indicates that preparedness in advance of hazard events is of utmost importance in order to reduce losses, as manifested in international risk management policy and best-practice guidance (UNDRR, 2022; UNISDR, 2015). Moving away from reactive disaster management towards proactive disaster risk management, disaster preparedness is defined as the actions taken in advance of a hazard. These actions aim to build knowledge and capabilities 'to effectively anticipate, respond to and recover from the impacts' (UNDRR, 2017).

This thesis advances the conceptualisation of disaster preparedness by differentiating preparedness into long-term and short-term. Short-term preparedness encompasses the concept of e.g., emergency response preparedness (IASC, 2015) and anticipatory action (Anticipation Hub, 2023) meaning that preparedness actions are initiated by medium-range forecasts or warnings of potential hazards and their impacts. These actions are mainly focusing on 'getting ready' and reducing the potential impact of an event which is expected within the next days or hours. Depending on when hazard forecasts or warnings are received, there might not always be enough time to take appropriate actions. Therefore, this thesis focuses instead primarily on disaster preparedness from a long-term perspective which ranges from now (i.e., the present moment) until a forecast or warning is received (at which point the focus shifts towards short-term actions). Long-term preparedness is focusing on actions that, firstly, enhance risk awareness and knowledge of local hazards, secondly, risk reduction, and, thirdly, strengthening coping capacities. Yet, the adoption of (long-term) preparedness actions is often hampered by the uncertainty of not knowing if and when

[2] Note: Throughout this thesis, the word 'we' refers to people in a generalised way, inviting the reader to consider (alongside the author) how they would feel or behave in the particular situation described. This word is used as a communication tool; therefore, I want to acknowledge that it is not my intention to imply that all people behave, feel, or react in the same way in a given situation. Indeed, individuals each have different characters, resources, opportunities, etc., which shape risk behaviours in specific ways in time and space.

a hazard may occur and what the impact may be. With this specification, long-term preparedness is closely related to the concepts of disaster mitigation and climate change adaptation.

This chapter builds the scientific basis for the following chapters by reviewing, firstly, factors shaping our disaster preparedness motivation, secondly, the no-regrets approach as a strategy to overcome uncertainty (amongst other challenges), and lastly, methods and tools that can be adopted to facilitate long-term preparedness under uncertainty.

2.1 What shapes our motivation for disaster preparedness?

This section will review commonly acknowledged influencers of preparedness behaviours which are organised thematically in relation to the empirical studies (Chapter 4-6) and are inter alia building the foundation for the framework for individual and collective long-term preparedness developed in Chapter 7.

The knowledge-action gap. Taking disaster preparedness actions firstly requires that we are aware of certain risks and have information on how to prepare for these (Entorf & Jensen, 2020; Kuang & Liao, 2020). For this, availability and access to information is key. Innumerable awareness raising campaigns and education material on disasters and preparedness have been created throughout the past years and even decades, further enhanced through the first priority of the Sendai Framework for Action (UNISDR, 2015). However, individual preparedness levels remain low in many areas around the world (Bubeck, Botzen, Kreibich, et al., 2012; Entorf & Jensen, 2020; UNDRR, 2022). Hence, the ambition of individual (long-term) preparedness may often appear as an unreachable ideology stemming from research and policies. It is being argued that raising awareness through campaigns or similar is not sufficient to trigger preparedness behaviour in us (Abunyewah et al., 2018; Hoffmann & Muttarak, 2017; UNDRR, 2022) because we are often only ‘passive recipients’ rather than actors or knowledge creators (Nikkanen et al., 2023). As a result, practices of top-down information sharing on risks and disaster preparedness is generally not seen as the most effective way to raise awareness and trigger actioning (Heidenreich et al., 2020). *Considering that preparedness behaviour is building on decision-making, there is a broad range of factors which are acknowledged to shape this process* (Kuhlicke,

Seebauer, et al., 2020; Rufat et al., 2020; UNDRR, 2022). *Identifying and understanding these factors can help to shape i.e., communication and education strategies, and to bridge this so-called 'knowledge-action gap'* (Rufat et al., 2020). *The following will briefly introduce the factors which are discussed within this thesis: previous hazard experiences, risk perception, self-responsibility, coping appraisal, and further decision-making criteria. Moreover, this knowledge-action gap will be further approached with different methods and tools in Chapter 9.*

Previous experiences. Experiencing flooding can become a 'game changer' (Platt et al., 2020) for our disaster preparedness since these experiences can increase our risk awareness and encourage us and our community to prepare for potential future events (Kuhlicke, 2013; Kuhlicke, Masson, et al., 2020). Learning from experiences can occur at different levels: individual (Kuang & Liao, 2020; Kuhlicke, Masson, et al., 2020), community (Carone et al., 2019), organisational emergency management (Kreibich et al., 2017), policy (Kuang & Liao, 2020; Surminski et al., 2020), or similar. For us, the learning process includes the translation of our experiences and our reflections on them (perhaps including regrets) into knowledge, self-responsibility, and finally, into adaptive and preventive actions to strengthen our capacities to cope with future flooding (Köhler et al., 2023; Kuhlicke, Masson, et al., 2020). Nonetheless, experiences do not always trigger our motivation to prepare (Kuang & Liao, 2020). In fact, it is likely that we only learn from our experiences when the event exceeds our own capabilities (Cutter et al., 2008). Hence, usual or less than usual flooding may not always trigger a learning effect. Moreover, we may not be prepared for a more extreme (than usual) flooding (Kates, 1962).

Summarising, experiencing flooding can become a motivational and educational factor for taking preparedness actions for the future (Nicklin et al., 2019). *The issue is that there is (and will perhaps always be) a large number of citizens around the world who have not experienced flooding (or other hazards) yet, and therefore, may not be aware of hazards, nor motivated to prepare for potential future hazards* (Hagelsteen & Becker, 2019; Hoffmann & Muttarak, 2017). *Moreover, we may be facing new hazards or higher magnitudes of known hazards (e.g., induced by climate change). Therefore, this thesis aims to derive lessons learnt from citizens' flood experiences in Germany in*

2021 to enhance the preparedness of citizens, in general, but with special focus on citizens who have not experienced flooding before.

Risk perception. Our subjective belief about a certain risk - risk perception - is important for explaining individual action motivation (Bubeck et al., 2013; de Guttry & Ratter, 2022; Felletti & Paglieri, 2019). Hence, risk perception reflects our own assessment of potential immediate or future threats. This threat appraisal may build on our proximity to the hazard, the character of the hazard, potential impacts, previous experiences, awareness of and knowledge on the hazard, the uncertainty of the threat, and other socio-economic, cultural, demographic factors (de Guttry & Ratter, 2022; Karlsson et al., 2023; Lechowska, 2018). In addition, risk perception and preparedness motivation can be impacted by cognitive biases such as wishful thinking or drawing on recent experiences (availability bias) (Kuang & Liao, 2020; Merz et al., 2015), but also by our emotions such as fear (Rogers, 1975). While risk perception is building on our factual knowledge (i.e., existing flood risk areas), our imagination aims to convert hazard information into mental pictures, potential actions, and emotions (Bulley & Schacter, 2021; de Guttry & Ratter, 2022; Karlsson et al., 2023; Sobkow et al., 2016). Meaning that if we are aware of a potential flood but cannot imagine it, neither the situation nor our actions and emotions, then the perceived risk may be lower.
To date, there is little research on imagination within disaster literature. Empirical studies i.e., Kuhlicke (2010) *do acknowledge the influence of imagination on disaster preparedness actions based on their study results, but do not dive deeper into the topic and neither the connection to risk perception. In response to this research gap, Chapter 4 will explore disaster imagination, its linkage to risk perception, and its influence on disaster preparedness through the German case study described in Chapter 3.*

Responsibility. Our perception on disaster preparedness responsibilities can be an additional barrier to preparedness. There has been a recent shift in disaster risk management and governance in which citizens are gaining more responsibilities as manifested in policies and laws. However, these new responsibilities are not always perceived or understood by citizens because they are often not part of the allocation process (Kuhlicke, Seebauer, et al., 2020; Monteil et al., 2022). In addition,

responsibilities are not always clearly communicated by authorities and hence, many citizens are not aware of their responsibilities which leaves them unprepared (Saikia et al., 2024). The perception of (self-)responsibility is highly subjective and linked to our perceived capabilities. In this regard, studies highlighted that many citizens are perceiving that governments remain responsible for disaster preparedness (and management in general) (Nikkanen et al., 2023), and that even living in risk areas they may not acknowledge their own responsibility (Heidenreich et al., 2020). These differing understandings of responsibilities by disaster risk management and governance actors can cause that expectations by citizens are not met if a hazard occurs which can lead to distrust in local authorities and the government (Felletti & Paglieri, 2019; Nikkanen et al., 2023). These different understandings of responsibilities are analysed in this thesis through the lens of social contracts – imagined/perceived by citizens, practiced by disaster risk management and governance actors, and legal-institutionally manifested (Blackburn & Pelling, 2018).
The concept of social contracts is relatively new and, therefore, has a limited evidence base on how social contracts are shaped and operated within different risk governance structures. Chapter 5 will apply this lens of (risk) social contracts to explore gaps between different social contracts in context with the floods in Germany. Furthermore, the chapter aims to expand the knowledge on the expected responsibilities of local authorities and governments by citizens, and hence, to derive ways forward to minimise this gap and enhance self-responsibility but also empower citizens.

Coping appraisal. According to the theory of protection motivation (Rogers, 1975), we unintentionally set our threat appraisal in context with our coping appraisal that is based on our self-efficacy – the ability to act and to self-organise (Kievik & Gutteling, 2011). Yet, our self-efficacy builds not only on the ability itself but rather on our belief to be able to do something (Heidenreich et al., 2020; Wang et al., 2022). In addition, time (Alonso Vicario et al., 2020; Taheri et al., 2023), resources (Arbon et al., 2013), and costs of actions (Sunderrajan & Albarracín, 2021; Wang et al., 2022) are playing a major role in disaster preparedness. An assessment of these factors combined are shaping our own coping appraisal. It was indicated that only if our threat and coping appraisal are comparable, we intend to take actions (Kuhlicke, Seebauer, et al., 2020). Hence, preparedness actions need to comply with our capacities; thus, they should

be easy to implement, can be taken in advance, require no or less resources, and be of low costs.
This existing knowledge will be integrated into the development of the disaster preparedness framework in Chapter 7.

Decision-making. Decision-making on actions and inactions in the context of disasters can be explained by different theories. In some cases, when fast decision-making is necessary, heuristics (mental short cuts) are primarily describing our behaviour (Nalau et al., 2021; Taheri et al., 2023) but our behaviour might also be driven by reflex or panic (Xenidis & Kaltsidi, 2022). More controlled behaviours are commonly a result of decisions taken based on our own evaluations of the outcomes of potential actions (Sunderrajan & Albarracín, 2021). These evaluations include that we consider the costs of actions, potential benefits, or positive outcomes of taking these actions, and foremost, whether we would regret having taken these actions in the future (Robinson & Botzen, 2018; Sunderrajan & Albarracín, 2021).
Regret as an outcome of decision-making, action taking, or inaction has been broadly discussed in psychological studies (Baum, 1999; Feeney et al., 2005; G. Feldman & Chen, 2019; J. Feldman et al., 1999; Sunderrajan & Albarracín, 2021; Zeelenberg et al., 2002; Zeelenberg & Pieters, 2007). *However, little is known about what we regret in context with our decision-making on disaster preparedness actions (or inaction). Knowledge on what we regret and especially, why we regret, can be valuable for communicating advice to citizens on individual and collective disaster preparedness*. *In this regard, Chapter 6 explores the flooding event in Germany from a regret perspective to gain a better understanding of regrets on disaster (un)preparedness*.

Decision-making under uncertainty. The fact that we are unsure about how our actual future will look like, challenges our decision-making; thus, the more uncertain the future is, the more difficult decision-making can be (Yusoff & Gabrys, 2011). Uncertainty was described as ‘a state of mind characterised by doubt’ (van der Keur et al., 2016). It reflects that something is unsure which is commonly linked to limited knowledge, data, or information e.g., how future climate will be like (Cambridge Dictionary, 2024; van der Keur et al., 2016; Walker et al., 2003). Despite we may not be

aware of it, we take many decisions under deep uncertainty throughout our life; one example is the path we choose to take after school (Marchau et al., 2019) .

Globally, we are facing different degrees of uncertainty from different sources (e.g., the lack of knowledge) and on different topics (e.g., hazard occurrence, impact). One common ambition in science is to reduce the uncertainty by addressing its source, for instance, by advancing forecasts and climate modelling (IPCC, 2014; Kox et al., 2015). However, there is a need to accept a residual level of uncertainty in disaster risk management and accept that we must take decisions in that uncertain environment (Rio Declaration 1992 (A/CONF.151/26)).

From our perspective as individuals (probably non-scientists), uncertainty may be perceived greater because we may have less information and knowledge about the randomness of nature and the atmosphere than scientists and eventually policy makers may have. Therefore, uncertainty in decision-making on (long-term) disaster preparedness remains a major challenge for us and hence, we may decide to do nothing instead (IPCC, 2012; Klima, 2019). *To note that this assumes that citizens are aware of potential risks. Uncertainty in decision-making is one of the major themes of this thesis and is primarily discussed in Chapter 7. The following section will focus on strategies for decision-making under uncertainty.*

2.2 How to overcome uncertainty for long-term preparedness?

This section will introduce the no-regrets approach as a strategy for decision-making under uncertainty which is used in various scientific disciplines, economy, and policymaking. This review will build the foundations of the framework for individual and collective (long-term) disaster preparedness which will be developed in Chapter 7. Nature-based Solutions are often categorised as no-regrets actions considering their potential co-benefits for the environment, society, and economy. Hence, they are used in this thesis as an example case study of no-regrets interventions. In this section, the no-regrets character of Nature-based Solutions is introduced and questioned which builds the basis for Chapter 8.

Towards no-regrets. For decision-making under deep uncertainty, it is important not to wait to receive a flood warning (which we perhaps will not receive) and only then start acting. In contrast, it is suggested to focus on long-term preparedness which

involves the monitoring of the evolution of the future and adapt to it when receiving new information and knowledge (Marchau et al., 2019).

As we have seen, uncertainty challenges our decision-making but on the other hand, we cannot avoid it either. Various strategies are available to deal with the challenges of uncertainty (Marchau et al., 2019). One strategy is to, firstly, develop multiple future scenarios, secondly, take robust decisions and actions which entail benefits in every scenario, and, thirdly, adapt these scenarios and actions according to new knowledge and information in the future (Woodruff, 2016).

Robust actions can be considered as a no-regrets move which, compared to options and big bets, considers positive outcomes in all scenarios and minimal regret (Courtney et al., 1997). The no-regrets approach has a long and interdisciplinary history. Already in the 1990s, the approach was adopted globally as a response to climate change inaction which resulted from deep uncertainty (Plume, 1995). In the disaster context, the no-regrets approach aims to support the enhancement of 'adaptive and proactive risk management [...] strengthening action under uncertainty' (Geyer et al., 2015). In this regard, no-regrets actions can increase our knowledge and ability to cope with disasters and hence, our preparedness for an uncertain future (IUCN, 2014).

To date, the no-regrets approach was adopted for climate change mitigation (Crusius, 2020; Plume, 1995) *and adaptation* (Auld et al., 2006; Hallegatte, 2009)*, and for disaster risk reduction* (Heltberg et al., 2009) *at different levels such as watershed* (Barrios et al., 2009) *or (sub)national level* (Geyer et al., 2015; Tingem & Rivington, 2009). *However, the potential of the approach for enhancing individual and collective disaster preparedness has not been explored yet. Therefore, Chapter 7 will aim to tailor the approach to guide citizens in their disaster preparedness under uncertainty.*

The no-regrets of Nature-based Solutions (NBS). As we have seen, the no-regrets approach was increasingly used for climate change adaptation and disaster risk reduction. As part of this movement, the approach was primarily used in environmental conservation (Barrios et al., 2009; Carvalho et al., 2011; Geyer et al., 2015) and, nowadays, broadened to the concept of Nature-based Solution (Debele et al., 2023). Nature-based Solutions aim at 'protecting, sustainably managing and restoring natural or modified ecosystems' (Cohen-Shacham et al., 2016). In addition,

NBS have the potential to alleviate societal challenges defined by the IUCN (e.g. disaster risk reduction, climate change adaptation); and evoke additional benefits (so-called co-benefits) for the socio-economic system such as health and well-being, employment, or social cohesion (Kabisch et al., 2016). Specific NBS can also be applied by individuals and implemented on their property or as a collective action for communities (Gonzalez-Ollauri et al., 2023; Koppelaar et al., 2021).

The current trend of NBS is to a great extent reasoned by the potential co-benefits and additionally, by their focus on sustainable development and nature preservation (Cohen-Shacham et al., 2016), their lower costs compared to engineering solutions (Raymond, Frantzeskaki, et al., 2017), their potential for participatory action (Giordano et al., 2020), their easier permission process (Amirzada et al., 2023), and their flexibility (Debele et al., 2023). In this regard, Nature-based Solutions are sometimes referred to as no-regrets actions.

Nature-based Solutions are often promoted by highlighting that the implementation of an NBS will likely not be regretted if no hazard will ever occur because of their co-benefits for the society, economy, and of course for the environment. Considering this overemphasis on the co-benefits, it is necessary to assess the potential impact of co-benefits. Co-benefits are not only used to promote NBS, but they also constitute one criterion in NBS selection processes (European Commission, 2021; Kuller et al., 2019). *Scepticism around the actual impact of NBS calling for a better understanding on the co-benefits but also potential disbenefits* (Seddon et al., 2021). *A multitude of frameworks and methods for assessing co-benefits was developed* (Calliari et al., 2019; Giordano et al., 2020; Kabisch et al., 2016; Liquete et al., 2016; Raymond, Pam, et al., 2017). *Yet, these frameworks fail to actually quantify co-benefits and largely neglect potential disbenefits. Addressing this gap, a practical framework for quantifying co-benefits and disbenefits of NBS is developed in Chapter 8.*

2.3 How can the uptake of no-regrets actions be facilitated?

The no-regrets approach can be a valuable approach for citizens' preparedness since it promises a satisfactory outcome in every of the many future scenarios. Yet, despite having identifying actions that are of low costs and may entail (co-)benefits, it does not mean that we are implementing these actions immediately, for instance, because some of the earlier discussed barriers may remain. This raises the need for bridging

science to practice for facilitating the uptake of disaster preparedness behaviour by citizens. With the focus of this thesis and especially, Chapter 9, this section will delve into different approaches to overcome barriers to (long-term) preparedness and motivate a disaster preparedness behaviour.

The value of collective action. Fostering bottom-up approaches to complement traditional top-down structures, is a common need in disaster risk management around the world (Matczak & Hegger, 2020). For this purpose, it is necessary to enhance the confidence or self-efficacy of citizens, including their feeling of self-responsibility, their capacities, and resources to take action (Felletti & Paglieri, 2019), because the feeling of being powerless or the doubt about being able to influence the impact is often resulting in inaction (Bubeck, Botzen, & Aerts, 2012; Kuhlicke, Seebauer, et al., 2020). Bottom-up initiatives - which may emerge e.g., through grassroots civil society or be fostered by local authorities - have shown positive impacts on individuals' self-responsibility and capabilities to take action through collective action, increasing social responsibility but also social learning (Dittrich et al., 2016; Gaillard, 2010; Kuang & Liao, 2020; Soetanto et al., 2017; Thaler & Seebauer, 2019). For instance, in the UK, many local floods action groups were founded in the aftermath of a flood or due to existing flood risk. These initiatives promoted household preparedness, but also started dialogues and collaboration with local authorities (Dittrich et al., 2016; Forrest et al., 2017; J. C. Morris et al., 2019).

In this regard, community-based initiatives can be valuable in the process of balancing top-down and bottom-up interactions because they can function as a mediator between citizens and local authorities whereas their actual engagement can be of different types i.e., contractual or cooperative (Geaves & Penning-Rowsell, 2015; McEwen et al., 2018). Yet, it is also acknowledged that the effectiveness of the collective action can be dependent on the structures and support of local governments but also on the community's ability to act cohesively (Ireland & Thomalla, 2011; Titz et al., 2018).

Overall, the need to move beyond public involvement and start civil dialogues to engage citizens and citizen groups in a more impactful way is communicated (Chambers, 1983; Evers, 2012). Close, long-term, and multi-directional relationships between citizen groups and authorities can empower citizens through increased

awareness and the sense of ownership which in turn can enhance the citizens' willingness to take on more responsibilities (Felletti & Paglieri, 2019; Mees et al., 2018; UNDRR, 2022). However, to achieve this, it is important to not only ascribe responsibilities to citizens but to collectively agree on proposed arrangements. Furthermore, it can be beneficial if dialogues and collaboration is initiated by local authorities (Ansell & Gash, 2008; Emerson et al., 2012; Forrest et al., 2021; Snel et al., 2022).

Across literature, the benefits of collective action and citizen bottom-up initiatives on self-responsibility and individual preparedness, community resilience, and local disaster risk governance are being highlighted. Therefore, the value of collective action will be integrated into the no-regrets framework in Chapter 7. However, also challenges of these groups and barrier towards effective collaboration with local authorities are acknowledged in literature. To gain a better understanding on flood action groups as no-regrets action as well as on their value for facilitating disaster preparedness is discussed in Section 9.1.

Supporting decision-making on actions. For initiatives, it can be difficult to identify most suitable solutions for their area as they may not be experts; thus, do not have sufficient knowledge or resources (Gonzalez-Ollauri et al., 2023). This can be especially the case for Nature-based Solutions as they sometimes require specific knowledge (e.g., on soil, ecosystems, etc.).

The increasing adoption of NBS for disaster risk reduction stresses the need for frameworks, tools, guidance, and methods to support the NBS selection process. In recent years, a variety of tools were developed, for instance, in form of a matrix (Gómez Martín et al., 2020; UNALAB, 2019), a hydrological landscape approach (Guerrero et al., 2018), or in catalogue form (NWRM, 2015b). These tools are informative but are lacking a holistic framework. A few decision-support tools were developed which aim at integrating various decision factors (Kuller et al., 2019; Mubeen et al., 2021; PEDRR, 2020). However, these decision-support tools can be highly demanding on data and modelling and thus, are not suitable for lay people to identify possible solutions for their specific area.

To fill the gap and support collective ideation on solutions and implementation of NBS (perhaps in collaboration with local authorities), a Nature-based Solution Toolkit

(Section 9.2) was co-developed with citizens and for citizens providing information and implementation guidance on different solutions to enhance collective action.

From passive recipient to knowledge creator. As we have seen, one barrier to preparedness behaviour is the fact that citizens are usually passive receivers of awareness raising campaigns or educational material. In this regard, one motivational factor that can be to turn passive recipients into knowledge creators (Nikkanen et al., 2023). To overcome this barrier, it is necessary to establish a multi-directional communication line where citizens can become co-producers of knowledge which can be more effective than traditional teaching methods (Mees et al., 2018; van Manen et al., 2015).

In the rise of participatory approaches, the main ambition has been to listen to local people and understand their needs; thus, empowering them to turn into the creators or sharers of local hazards and risk knowledge (Chambers, 1983). This is often performed in form of workshops applying various tools to foster engagement and mutual learning i.e., participatory hazard and vulnerability mapping (Klonner et al., 2021; Sullivan-Wiley et al., 2019), ideathons for brainstorming on adaptation measures (van Manen et al., 2015), or involving citizens in the selection process of adaptation measures (Anderson et al., 2022; Barquet & Cumiskey, 2018; Gonzalez-Ollauri et al., 2023). Another method is the idea of climate storylines (Shepherd et al., 2018) which can be used in participatory workshops. These may either focus on unpacking previous disasters or developing future scenarios (including worst-case scenarios) under uncertainty to gain a deeper understanding on risk factors, cascading risks, and potential impacts to feed preparedness planning for the future (Caviedes-Voullième & Shepherd, 2023). Citizen science is another example of participatory approaches. For instance, the usage of crowdsensing or crowdsourcing methods in educational activities (Adnan et al., 2023).

In order to enhance the uptake of no-regrets actions for disaster preparedness, participatory methods can be used to, firstly, increase the understanding and knowledge about risks by co-producing this local knowledge, and secondly, empower citizen (groups) to identify actions and solutions that are suitable for their area, community, or own property. In this regard, the solutions presented in Section 9.3 and 9.4 are building on the participatory concept.

A question of behaviour change. The review of factors influencing our disaster preparedness highlighted that they are greatly linked to our behaviour; thus, taking long-term preparedness actions can include a change in our behaviour. To motivate action taking, it is important to understand the background on behaviour change and, specifically, motivation. The behavioural theory presented in the COM-B model (Michie et al., 2011) describes that behaviour change is influenced by our physical and psychological capabilities, an opportunity prompting a change (i.e., a recent disaster event), and finally our intrinsic or extrinsic motivation. In this context, the no-regrets approach works along the two components - capability and motivation - while more focusing on the first one. This means that no-regrets actions are designed to not require a large set of knowledge and skills but rather are adoptable by (almost) everyone.

The key to disaster preparedness is motivation. Our motivation may be divided into intrinsic and extrinsic which basically means that we are motivated to do something because it may be fun or interesting (Wee & Choong, 2019). On the other hand, rewards in form of money, recognition, benefits, or similar are presenting an external motivation for us (Lewis et al., 2016). Looking at no-regrets actions, one motivation factor are the potential co-benefits which are often emphasised, especially, in context with Nature-based Solutions (Anderson et al., 2022).

One way to trigger our inner motivational force is through gamification and serious games which have gained popularity throughout the past decades. Even though they both inherit the word *game*, there is a difference between these concepts: firstly, gamification is a way of integrating gaming elements and mechanism into educational material, workshops, etc. Whereas serious games are actual games (Wee & Choong, 2019).

Using a gamification approach, different game design elements can be adopted for motivational purpose in i.e., educational material or technologies such as competition and challenges (Wee & Choong, 2019), rewards (Hamari, 2017; Lewis et al., 2016), or social interactions and networks (Douglas & Brauer, 2021). Even though gamification was found to enhance behavioural changes, the question remains whether these are short or long-term changes (Douglas & Brauer, 2021).

Serious games are primarily targeting to support education on certain topics, simulating potential (future) realities making the future more touchable, and promote

specific behaviours (Forrest et al., 2022). An earlier definition of serious games stated that they are computer-based games (Ritterfeld et al., 2009). One example is the video game FloodSim focusing on awareness raising of flooding in the UK (Rebolledo-Mendez et al., 2009). Another example is the integration of a topic, scenario, or feature into an existing video game such Nature-based Solutions into Minecraft (de Sena et al., 2023). Virtual reality is probably the most recent emerging tool to support learning about floods by being situated into a flooded area (Sermet & Demir, 2019), practicing flood safety (D'Amico et al., 2023), and much more. Throughout the past years, the definition of serious games has been broadening also including, for instance board-games (Mossoux et al., 2016; Terti et al., 2019).

To bridge the no-regrets science to the practical application of it, the COM-B model was adopted to create an app supporting the behavioural change with no-regrets actions (Section 9.3). Additionally, this app is designed applying the method of gamification to increase the motivation to use the app and take actions. Moreover, building on the idea of intrinsic motivation, a serious game (Section 9.4) was created empowering citizens to explore their local risk and identifying potential no-regrets solutions.

2.4 Summary

Disaster preparedness is one of the main priorities in disaster risk management because it can prevent the loss of lives, economic and structural damages, and much more. This thesis distinguishes between long and short-term preparedness. Long-term preparedness refers to the time frame starting from the present moment (perhaps with deep uncertainty about a disaster) until the forecast of a probable hazard. Successively, short-term preparedness then starts around the time of a probable forecast (hence lower uncertainty) until the event itself. In this sense, long-term preparedness includes mitigation and adaptation actions, while short-term preparedness focuses on emergency response preparedness and impact reduction.

Factors influencing our disaster preparedness behaviour. A large amount of research exists on different factors that can influence our motivation for preparedness. The primary factors reviewed in this chapter were flood experiences, perceived risk perception, feeling of self-responsibility, individual coping appraisal,

and decision-making habits as well as the challenge of uncertainty in decision-making.

The review has highlighted that previous flooding experiences often have learning effects as citizens are reflecting on their past behaviour which sometimes leads to regret. However, as not all citizens can draw on previous experiences, it is important to learn from the experience of others and to understand additional influencing factors for disaster preparedness. With this ambition, the first objective aims to build on the experiences of citizens affected by the devastating floods in Germany in 2021 to fill the following gaps in research on factors shaping individual disaster preparedness actions and inactions (Chapter 3-6).

Risk perception as a driving factor for disaster preparedness has been broadly discussed in research. Yet the influence of individual's imagination on risk perception has been mentioned but was not explored to date. To gain a better understanding on the relation between imagination and risk perception, Chapter 4 will analyse the experiences of citizens towards the influence of their limits of imagination on their disaster preparedness behaviour.

Despite not being a part of many behavioural theories on disaster preparedness, the responsibility was acknowledged as an influential factor across research. With the concept of social contracts, it was highlighted that there are different perspectives on disaster risk management responsibilities. To explore the different perspectives and their influence on disaster preparedness, Chapter 5 situates the perceived responsibilities by citizens within the legal-institutional responsibilities manifested in Germany.

Looking at decision-making as a psychological factor influencing our disaster preparedness behaviour, regret becomes an important aspect as we are taking decisions (if there is enough time) based on our appraisal of potential regrets of our actions. To date, research has not been focusing on regret in context with disaster preparedness. To fill this gap and to enhance long-term disaster preparedness – where time is not a limitation for decision-making – Chapter 6 dives into the regrets and no regrets of citizens who were affected by flooding.

Disaster preparedness under uncertainty with no-regrets. Uncertainty is a well-known challenge in decision-making whether in business decisions, decisions on our

professional path, or in disaster context. The no-regrets strategy was adopted in various disciplines to take decisions under uncertainty. Especially, in the context of climate change, this strategy was integrated as a way around inaction due to uncertainty at various levels - from local to international. Since uncertainty about hazards remains a challenge also for citizens and hampers the uptake of preparedness actions, Chapter 7 aims to gain a better understanding of the no-regrets approach and how it can be framed to assist citizens in individual but also collective disaster preparedness.

One category of no-regrets actions is Nature-based Solutions to reduce local risk. These solutions are often referred to as no-regrets actions because they shall be more cost-effective than engineering solutions, be flexible, easier to get permission for, and foremost they are promised to entail various co-benefits which shall reduce potential regrets about their implementation if no hazard occurs in the future. Despite the promotion of co-benefits, their actual measurable impact remains unclear. To ensure, that NBS are no-regrets solutions, Chapter 8 focuses on ways to pre-assess the co-benefits but also potential disbenefits in a quantitative way.

Facilitating the uptake of no-regrets actions. The knowledge-action gap is being discussed in science also as research highlighted that awareness campaigns are not always very successful in facilitating action taking in disaster context. The literature review introduced different ways that can support the facilitation of disaster preparedness behaviour which is discussed in Chapter 9.

The value of collective action (e.g., of flood action groups) in promoting individual self-responsibility and disaster preparedness was underlined in research. Yet, the reality of these groups may be very different depending on, for instance, the collaboration with local authorities. Hence, Section 9.1 will discuss insights gained from German flood action groups on the uptake of flood action groups and their potential to facilitate action around their community.

The uptake of Nature-based Solutions is greatly promoted but it requires specific expertise, resources, and capabilities to identify suitable solutions for an area. To bridge the scientific knowledge on their suitability criteria to citizens (and practice in general), Section 9.2 presents an NBS Toolkit for citizens to learn about NBS, get

recommendations on suitable NBS for their area, and guidance on the next steps towards the design and implementation.

The facilitation of disaster preparedness behaviours is likely to include a change in behaviour. Hence, the uptake of no-regrets actions needs to be facilitated with a behavioural perspective. Building on the COM-B behaviour change theory, a gamified app was developed to facilitate the adoption of no-regrets actions (Section 9.3).

Lastly, in regard to the knowledge-action gap, the fact that citizens are often simply passive receivers is one driver of this gap. To bridge this gap, one method can be to turn citizens into knowledge producers and empower them to identify solutions for their local issues. Building on these scientific findings, a serious game was developed to facilitate this knowledge production process by building on the participatory approach (Section 9.4).

3 Methodology

This chapter describes the applied methodology of the empirical chapters 4-6 by introducing, firstly, the philosophical approach (Section 3.1), secondly, the case study context of the German floods in July 2021 (Section 3.2), and finally, dives into the design of the questionnaire for data collection (Section 3.3).

3.1 Philosophical Approach

The main focus of this thesis (and particularly Chapters 4-6) is the recent flooding event in Germany in 2021, with the aim of understanding how citizens behaved before, during, and after the flooding event and why. After the flooding, several studies were conducted using different perspectives i.e., meteorological (i.e., Kreienkamp et al., 2021), disaster management (i.e., Fekete & Sandholz, 2021; Thieken et al., 2023), infrastructure resilience (i.e., Koks et al., 2022), etc. Some studies explored the perspective of citizens through surveys (i.e., Thieken et al., 2023; Truedinger et al., 2023). These studies applied a quantitative methodology which raised important points but are limited because they do not further explain the reasoning behind the findings, nor do they encourage citizens to express themselves. This thesis aims to move beyond existing studies by giving affected citizens a voice to share their experiences and challenges, to express their opinions, and to communicate their ideas.

A qualitative approach. This aim follows previous studies with a questionnaire-based methodology. However, in this thesis, the emphasis is qualitative rather than solely quantitative measures. A qualitative methodology was chosen to explore the perspective of citizens in more depth and to gain a deeper understanding of underlying reasons e.g., for their preparedness (in)action.

Case study. With the aim of this thesis to explore what encouraged (or not) citizens to prepare for the flood, a case study approach was selected to gain insights into the behavioural, institutional, and social contexts of the event. Case studies are a common approach in social science including in geography wherein the role of place in shaping and producing specific outcomes (which are sensitive to local cultures,

environments, social relations, and historical context) is key to the analytical lens. In contrast to other approaches (e.g., experiment, archival analysis, etc.), a case study is designed to 'investigate a contemporary phenomenon [the recent flooding event] within its real-world context [e.g., institutional and legislative structures, perceptions, behaviour, and psychology, etc.]' (Yin, 2018). Hence, applying a case study approach allows to contextualise the collected data and explore reasonings behind actions, inactions, and perceptions of participants. Having this in mind, an exploratory case study approach was chosen to be most suitable for the empirical part of this thesis.

The case study approach is regularly associated with biases of subjectivity in data analysis and interpretation, or limitations in generalising results. These are common misunderstandings as highlighted by Flyvbjerg (2011) who argues that firstly, quantitative methods are not less biases towards subjectivity than qualitative approaches (e.g., considering the design of closed questions), and secondly, knowledge from context-dependent cases can be highly valuable for learning which reflects the objective of the empirical study of this thesis. Furthermore, the author raises the point that case studies can generate insights which may be generalisable if e.g., participants are from a wider area, or the number of participants is higher.

The case study area was chosen to cover two states in Germany which encompasses diverse areas in terms of geography, demography, and more but are perhaps more homogenic in culture and from an institutional-legal perspective. Selecting a larger case study area shall support the identification of emerging themes across these diverse sub-areas. With this approach, theoretical insights can be developed which are either generalisable within Germany or beyond borders.

Questionnaire. The flooding affected various areas in Germany and primarily in the western part of it covering two federal states as well as the neighbouring countries of Germany. Considering differences in disaster risk and emergency management (e.g., early warning dissemination) (Snel et al., 2022), this thesis focuses only on the flooding within German borders as it is not the aim to compare different practices but rather to understand the citizen's perspective within a similar institutional, political, and cultural structures. Hence, the case study encompasses the two federal states Rhineland Palatinate and North Rhine-Westphalia which were most severely affected by the floods in Germany in 2021. Despite defining the geographical boundaries of the

case study, the area remains large and versatile for a qualitative study which would be resources intensive if other research methods (e.g., interviews or focus group discussions) were applied (Flowerdew & Martin, 2005). Focusing only on one community would allow gaining a more in-depth understanding but at the same time, it would limit the explorative potential of the study in terms of expanding scholarships. Having this in mind, a questionnaire (including open and closed questions) was selected as a data collection tool to capture the diverse perspectives of citizens, their experiences, opinions, and ideas, whilst maximising the sample size. The questionnaire is introduced in Section 3.3.

Social constructivism. This thesis adopts a constructivist epistemology by collecting the perspectives of several citizens including their different experiences, opinions, and more. In other words, the knowledge and theories that may be derived from this empirical study will be a construct of the experiences and opinions of the questionnaire participants. In this regard, this thesis acknowledges that the perspectives shared by participants are shaped by personal held values, assumptions and histories, and a range of intrinsic and extrinsic influences and therefore, the manner of self-reporting or recollection of events may differ between individuals (Ültanir, 2012). In particular, the constructivism acknowledges that participants may have different understandings of experiences and knowledge due to their own believes, ideas, and more. In addition, following the concept of social constructivism, the understanding and experiences shared by participants can be influenced by the constructed reality within their society or social networks. These differences do not undermine the validity of the results, but rather, this diversity of views and experiences constitutes a fundamental dimension of the research. Lastly, it needs to be noted that risk is subjectively defined, experienced, and responded to.

Positionality and bias statement. As the primary researcher of this case study, I want to acknowledge the possibility that my background and personal experiences may have influenced the design and dissemination of the questionnaire as well as the analysis and interpretation of the received responses. Growing up in the area of the case study, I have a deep understanding and connection to the local culture, society, politics, norms, and also issues. As this can be of value for the case study and

questionnaire design, it perhaps has raised biases affecting the research process. I acknowledge that my views and experiences are one perspective of many (referring also to social constructivist theory) and hence, I aimed to remain objective and open to the multitude of perspectives of the questionnaire participants. Furthermore, my personal understanding of local cultures, norms, and especially attitudes allowed me to better understand and feel with the flood affected people but could have led to biases in the data analysis and interpretation. Minimising this bias, my research outputs included many quotes; thus, other researchers are able to verify my analysis and interpretations from their perspectives. Due to my social network in this area, the beginning of the response collection might have been biased towards like-minded people (e.g., friends and family of mine), but I reduce this potential bias by changing the dissemination strategy to Facebook groups reaching out to people who I do not know.

3.2 The case study

This section introduces firstly, the case study area, secondly, disaster risk management and governance structures (Section 3.2.1), and thirdly, the flooding event in Germany (and its neighbouring countries) in July 2021, along with its impacts, and lessons learnt (Section 3.2.2).

Geographic boundaries. The flooding event in July 2021 was primarily affecting Western Europe including Germany, France, Belgium, Luxembourg, and the Netherlands. As the flooding event turned into a devastating event across the countries, Germany recorded a high number of fatalities raising concerns about the effectiveness of the flood (risk) management within the country. Considering this disastrous outcome and the post-event discussions circulating within the population and media, Germany was selected as the case study for this thesis. Not at last, my personal background (of being a German citizen), local knowledge, and language abilities, influenced the case study area selection. In Germany, several areas were affected but the west of the country most severely. Many studies used the Ahr valley as a case study due to the severeness of the (flash) flooding and its impact. However, as many other places in Rhineland Palatinate and North Rhein-Westphalia experienced more severe flooding, the case study area was not limited to the Ahr

valley, but I decided to expand it to these two states. Widening the geographic area of the study area was further decided on with the ambition to identify common themes that emerged from the experiences of the flooding and to enable the potential for generalising research findings.

3.2.1 Flood risk management in Germany

The flooding event in Germany needs to be explored within the flood risk management and governance structures at multiple levels, but also social structures. In this regard, the following will introduce the flooding history, institutional and legal structures, and the social capital of the citizens.

Flooding history. Flooding is not a new phenomenon in Germany. Throughout the history, flooding has occurred frequently due to overflowing streams and rivers across the country. However, the intensities of flooding are varying greatly. More recently, major flooding events were primarily cause by rivers such as the Elbe and Danube in 2002 and 2013. Local flooding events can be caused by different factors primarily linked to heavy and consecutive rainfall. This included flooding of small streams, urban flooding due to when sewage systems are reaching their capacities, and groundwater floods. These flooding events are often less severe and therefore, less reported on. In Germany, a few well-established catalogues are available reporting historic extreme precipitation events but not directly on historic flooding, especially flooding of streams or pluvial flooding.

Flood risk mapping. In accordance with the EU Floods Directive (2007), flood inundation and risk maps were homogenously developed for different return periods (10-20; 100; 200-year; and 'extreme') by 2013 and are updated every six years. Simultaneously, building codes were adjusted in coherence with the modelled flood risk areas (Kreienkamp et al., 2021; Vorogushyn et al., 2022). Flood hazard and risk maps are openly available for citizens in online portals of the federal states. In 2018, the second Omnibus Flood Control Act further restricted building codes with respect to 100-year flood risk areas (Surminski, 2020). Yet, flood hazard and risk maps are only available for fluvial flooding and further neglecting small streams. Nowadays, pluvial

flood hazard maps are increasingly computed to inform municipalities and their citizens about potential inundation areas (e.g., Mittelstädt et al., 2021).

Early warning system. Germany currently operates a modular early warning system (MoWaS) which was introduced in 2011 and is described as a multiplier system linked to various dissemination channels (online and analogue). The system is building on a top-down concept in which warnings are issued by the German Weather Service (DWD) that are then trickling down to federal states, to local authorities and, ideally, to the citizens. In order to operate during power outages, the system is built on satellites (Kreienkamp et al., 2021; Thieken et al., 2023). Before and during the flooding event in 2021, 288 warnings (and updates) were issued by the system (Thieken et al., 2023). The automated warnings are accompanied with predefined behavioural suggestions for citizens.

A first nationwide early warning test was performed in 2020 which highlighted many issues and inconsistencies leading to an expansion of the siren network and further improvements (also in response to issues that arose during the event in 2021). More recently, cell broadcasting was introduced which is applicable for most (but not all) mobile phones. Nowadays, the national warning test is being carried out annually (December 2022, September 2023, September 2024).

Flood risk management and governance. Germany's actors in flood risk management and their responsibilities are of a complex structure. As we have seen, at federal level, warnings are being issued which are supposed to trickly down through state and municipal level to arrive at the citizen's level. In addition, the Federal Office of Civil Protection and Disaster Assistance is acting as a support to the federal states who are primarily responsible for issuing warnings to local authorities. While local authorities are officially in charge of warning the public, coordinating preparedness, response, and evacuation actions (Thieken et al., 2023).

The federal states are further in charge of developing state level policies, laws, hazard maps, and more for riverine flood risk management. Besides municipalities, important sub-state level flood risk management actors include, for instance, river catchment authorities, fire brigades, voluntary organisations, and wastewater managers. More information on responsibilities is provided in Section 5.3.1.

Communities can be involved in local decisions and action such as landscape planning and volunteered response during disasters (Puzyreva et al., 2022). Citizens who are responsible for their private household and are 'obliged to undertake appropriate actions that are reasonable and within one's means to reduce flood impacts and damage' (Bubeck et al., 2012).

Back in 2008, the concept of shared responsibility was recommended by the German Water Association (Hartmann & Jüpner, 2020). However, several issues related to sharing responsibilities are still existing as highlighted by Snel et al. (2022): 1) citizens often declare the government to be liable e.g., for flood recovery taking away the accountability from themselves; 2) public participation in flood risk management is very limited; 3) citizens are less aware of legal frameworks; 4) responsibilities at different levels are not clearly grasped; and 5) moral responsibility is constantly moved between authorities and citizens. Furthermore, it was stated that citizens are volunteering as they feel it is their responsibility to help others.

Solidarity. The feeling of responsibility is also reflected in the solidarity between German citizens before, during, and after flooding events. Disaster solidarity is an important value observed in communities across several German flooding events. In particular, solidarity is described as social cohesion between citizens, collective action, or citizen volunteering to help flood affected people by e.g., providing shelters, physical assistance, or financial aid. For instance, solidarity was highlighted during the Elbe Flooding in 2013 (Albris, 2023) but also during the recent flooding in 2021 (Zander et al., 2023).

Risk management financing. The government has been providing funding for flood affected citizens in earlier times, for instance, after the flood in 2013, 60% of the citizens received recovery aid (Platt et al., 2020). This was (partly) terminated because, now, citizens are responsible for their home and property by law (Snel et al., 2022). As citizens are legally obliged to protect their properties and the government is not legally bound to provide flood recovery funding, citizens need to consider insurance and the implementation of protective measures. However, it was found that the willingness-to-pay for flood measures is very low (around 50 €) and that it is greatly dependent on risk awareness of the household (Entorf & Jensen, 2020). Insured residents were found

to be more willing to implement measures (Thieken, 2018). Furthermore, ownership was identified as a determinant for adaptive behaviour (Dillenardt et al., 2022) as well as flooding experiences (Bubeck et al., 2012). Discussions at federal level on whether insurance should be made compulsory are on-going since several years but remain without conclusions.

Legal framework. The primary legal framework is the Federal Water Act developed in 1960. This law defines guidelines for risk assessment, building regulations, and flood protection. In 2009, this law was updated reflecting the guidelines introduced by the EU Floods Directive (2007). In addition, the law was translated into state level laws. The two major flooding events in 2002 and 2013 initiated the development of the Omnibus Flood Control Act (2005 and 2017) which lays out that flooding is to be managed at catchment level and preventive flood risk management should be targeted. Also, the flooding in 2021 had an influence on the legal framework particularly on the Federal Government's Strategy for Strengthening Resilience to Disasters (2022), and the Climate Adaptation Law (to be finalised by end of 2024). More detailed information on the legal framework is provided in Section 5.3.1.

3.2.2 The floods in 2021

Following a three-week wet period, the low-pressure system named Bernd stagnated over Western Europe in Mid-July 2021 (Dietze et al., 2022). The pressure system caused large amounts of precipitation which escalated due to its stagnation over this area (Kreienkamp et al., 2021). The main countries affected by severe precipitation were France, Belgium, Luxembourg, The Netherlands, and Germany. In Germany, many areas experienced heavy precipitation over a few days whereas the federal states Rhineland-Palatinate and North Rhine-Westphalia

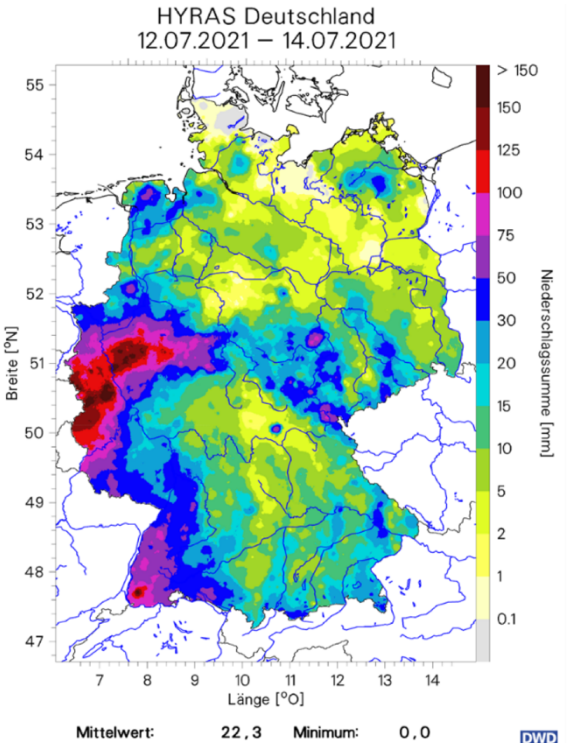

Figure 5: Precipitation over 72h in Germany between 12th and 14th July (Source: (Junghänel et al., 2021))

were most severely affected. In this area of Germany, precipitation amounts reached up to 190 mm within only 72 hours (Figure 5) (Junghänel et al., 2021).

The accumulated precipitation over 72 hours on moist soils led to their saturation ins short time. Resulting surface runoff caused various types of flooding i.e., rivers and streams in hilly areas rose quickly and exceeded their banks, sewage systems reached their capacities as well as water reservoirs which needed to be opened, or the groundwater table rose posing a danger from the bottom up. The valleys of the rivers Ahr (Rhineland Palatinate) and Erft (North Rhine-Westphalia) were most severely affected were flash flooding caused devastating damages. At the same time, many municipalities were affected by the various types of pluvial, fluvial, and groundwater flooding (Dietze et al., 2022; Junghänel et al., 2021; Lehmkuhl et al., 2022; Thieken et al., 2023).

Impacts. The event has been marked as one of the worst floods in Germany as the floods caused devastating social, environmental, and economic impacts around Germany.

More than 180 people lost their life in the floods because of drowning in the car, in basements, and on the streets, or due to other reasons such as heart failure or burning injuries (Dietze et al., 2022; Thieken et al., 2022). In total, more than 40 000 citizens were affected by the floods in Germany (Fekete & Sandholz, 2021). Moreover, many people have been (or still are) suffering from mental health impacts such as post-traumatic stress disorder and sleeping disturbances (Zenker et al., 2024).

The flooding caused major damages on critical infrastructure with an overall economic estimation of more than EUR 32 billion (Mohr et al., 2022) including residential buildings and public infrastructures such as bridges, railways, roads, schools, but also the electricity network (Koks et al., 2022). These damages became obstacles for disaster management i.e., power outages interrupted the dissemination of early warning, or damaged bridges and roads hampered evacuation, response, and recovery efforts (Fekete & Sandholz, 2021).

In addition, several environmental impacts were reported such as the contamination of streams and rivers due to substances (e.g., oil, waste, sewage water) entering the flood water (Lehmkuhl et al., 2022). Furthermore, environmental destructions i.e.,

through landslides or removed trees changed the natural structure of some rivers or streams (Dietze et al., 2022).

Lessons learnt. Existing literature and reports contain a large number of conclusions regarding risk awareness and mapping, early warning, collaboration, plans and trainings, and relief operations. In regard to risk mapping and impact modelling, issues around the flood sensing infrastructure (Dietze et al., 2022), the lack of stream flood protection plans (Fekete & Sandholz, 2021), and the need for integrating flow velocity integration (Koks et al., 2022) were highlighted while it was suggested to introduce a shift to impact-based forecasting (Apel et al., 2022).

Major lessons learnt were identified from the early warning system and communication. System-wise, warning channels need to be more diversified to become infrastructurally independent (Fekete & Sandholz, 2021). Communication-wise, messages need to be more customised to suite different flood types and audiences but also, they need to be better integrated into flood risk management actions and interactions (Bosseler et al., 2021). Furthermore, the interpretation of messages remains an issue (Fekete & Sandholz, 2021) while it was suggested to introduce more levels of warnings (Thieken et al., 2023).

Overall, collaboration between experts, authorities, and citizens need to be enhanced (Koks et al., 2022; Mohr et al., 2022) and (worst case) scenarios, emergency plans, and exercises need to be developed to better understand each actor's role and for citizens to be able to prepare and respond independently (Bosseler et al., 2021; Fekete & Sandholz, 2021). In addition, more work on awareness raising of hazards and disaster behaviour is needed, especially with younger and older generations (Thieken et al., 2022). From the perspective of emergency services, an evaluation showed the need for transportation devices that can be used in different terrains and weather conditions but also, staff needs to be trained for various types of climatic hazards (Kippnich et al., 2022). Furthermore, psychosocial support is needed to assist citizens in coping with mental health impacts during and after the event (Zenker et al., 2024).

It was highlighted that response and recovery actions were often organised spontaneously – without using official bureaucratic processes – to be able to act faster (Bosseler et al., 2021). In some cases, social media was used to organise fast help between citizens (Kühne et al., 2021). Moreover, false expectations were dominantly

hampering efforts, for instance, expectations between authorities or other disaster management actors (Fekete & Sandholz, 2021).

3.3 The questionnaire

An online questionnaire was designed for the collection of the experiences, opinions, and ideas of flood affected citizens in Germany. This section introduces the questionnaire as the data collection tool for the case study (3.3.1). Following this, the applied data analysis method is described (3.3.2) and limitations of the study are explained (3.3.3).

3.3.1 Data collection

Spatial focus. The questionnaire was disseminated in the two most severely affected areas during the flooding event in 2021. These areas encompass the two federal states Rhineland Palatinate and North Rhine-Westphalia in the western Germany. People living in this region have experienced different types and magnitudes of flooding (i.e., flash flooding, river flooding, sewage flooding, or groundwater flooding).

Participants. The survey aimed to gain insights into the perspective of citizens on this event. For this purpose, the questionnaire invited any person living in flood affected areas in Rhineland Palatinate and North Rhine-Westphalia. The participant group was only limited by these spatial boundaries and a minimum age of 18 years. This minimum age was selected to avoid ethical issues related to the need for permissions for participation by parents or guardians of children.

Question design. The questionnaire (Appendix 1-2) was designed to gain an overview. From this overview, emerging themes, patterns, and theories could be distilled. In total, the questionnaire included 26 questions (15 close and 11 open questions) which covered the following topics:

- *Survey consent*
- *The flooding:* flooding experience, source of the flood, awareness on elements that increased or prevented flooding
- *Preparedness and response actions:* which actions were taken in advance and when the water arrived

- *Perceived flood preparedness:* preparedness feeling before, during and after the flood, what caused (or not) the feeling of preparedness
- *Early warning:* timing of a first warning reception, warning sources
- *Flood expectations:* the expected likelihood severity of flooding and being affected, influence of risk communication on preparedness behaviour
- *Adapted behaviour for future flooding:* how people would act differently in the future, which warning sources they would trust most, knowledge on risk areas
- *Personal opinions on the event and improvement suggestions for the future:* how communication could be improved, which responsibilities participants ascribe to themselves and which to authorities, the main issues and how could these be prevented in the future, willingness to be more engaged in local activities
- *Respondent variables:* postcode, age group, living situation

The questions were designed either in a descriptive or analytical manner. In other words, some questions were designed so that participants could describe what happened or how they acted while others were asking for reasons and hence, in an analytical manner.

Piloting and refinement. The first version of the questionnaire was piloted with family members and friends of mine who were affected by the flooding directly or indirectly. The feedback and initial data received was used to improve the questionnaire by clarifying and adjusting questions as well as correcting spelling mistakes.

Ethical consideration. The final questionnaire was submitted to the SAGES Research Ethics Committee of the University of Reading approved by the committee on 14th February 2022 (SREC2022/24). In alignment with the ethical agreement, survey participants approved the informed consent before filling in the questionnaire. The consent informed about that 1) the participation is anonymous and voluntary, 2) the participants can withdraw from the survey at any time, and 3) the data provided by participants will be stored securely and can be made available in an anonymised format upon reasonable request. In addition, the consent mentioned that participants can request a copy of their own data.

Since flooding events can be very traumatising and cause distress to people in the immediate aftermath but also a long time after, the consent form further included recommendations on potential advisories the participants could contact to receive support to cope with the mental health impacts of the flooding. Furthermore, it was highlighted that participants can withdraw from their participation at any time without giving a reason.
Moreover, the questionnaire dissemination was timed so that considerable time has passed since the devastating event. Secondly, the timing was influenced by the questionnaire development and ethical approval processes.

Influence of Covid-19. The flooding event occurred during the Covid-19 pandemic causing further challenges to disaster management. Regarding this study, the pandemic situation may have additionally distressed the participants before, during, and after the flooding. Furthermore, the management of the pandemic on a governmental level was largely criticised by the population which may have led to decrease in trust in the government even before the flooding event. In addition, it arose from the survey results that those warnings issued by the national warning app (which was also used for Covid-19 related warnings) were not taken seriously by some participants because they have received too many warnings during the past months and even year.

Dissemination. After the ethical approval of the questionnaire, it was open for responses in German and English language between March and July 2022. The questionnaire was disseminated in an online version through Microsoft Forms. The dissemination strategy was focusing on social media channels to make it easily sharable. The following channels were used: WhatsApp, Twitter (now X), LinkedIn, and Facebook. In the first round, I posted the questionnaire via my private channels with the request to share it. In a second round, I posted the questionnaire in different public and private Facebook groups of regions that were affected by flooding and in groups that were founded during or after the flooding event which targeted at allocating help between the citizens. Most responses could be collected through these Facebook groups.

3.3.2 Data analysis

In total, 438 responses were downloaded from Microsoft Forms into a Microsoft Excel file. Before the data was analysed, English responses were translated into German using Google Translate. Furthermore, provided postcodes were corrected i.e., a participant wrote two postcodes – one from the home during the flooding and the other one of the new homes (after the flooding). Additionally, the municipality, district, and state names were added based on the postcodes.

For closed questions, descriptive statistics were used to derive percentages of i.e., age groups, living situations, and flood experience. Some closed questions were transformed into numbers to analyse the change. For instance, participants indicated what they expected to happen and what actually happened; thus, to define whether citizens under or overestimated the event, the numeric approach was used.

Most of the responses used in this study were analysed qualitatively. Recalling that the aim of this study was to derive themes which emerged throughout the responses of different participants, the thematic analysis was utilised. The thematic analysis (Braun & Clarke, 2006) included the following steps: the first step encompassed an initial familiarisation with the responses. For this step, the software NVivo (release 1.7.1) was applied to browse responses from different questions. Using NVivo, this familiarisation stage focused on performing an initial coding of responses which was important for the next step. Based on the initial coding, overarching themes (e.g., regret, responsibility, and imagination) could be distilled. To delve into these themes, Microsoft Excel was used to code responses into subthemes and highlight important quotes. These were then applied as the basis for the following three research articles presented in Chapter 4-6.

3.3.3 Limitations

The design of the questionnaire and its dissemination strategy encountered the following limitations:

- The major aim was to distil emerging themes from the responses which were thematised by participants. The methodology and methods applied for this were very suitable and important. However, it was limiting in the way that the questionnaire did not allow to delve any deeper into the reasoning of some responses. Therefore, it can be concluded that for a scoping purpose, the study

design was sufficient, yet it can be recommended to use different qualitative methods to gain a deeper understanding of one of the emerged themes. For instance, focus groups or interviews would provide more insights into reasoning of participants i.e., why participants decided on something. Hence, studies on a specific theme could be enhanced using mixed methods (e.g., questionnaire and a follow up focus group discussion).

- The selected questions provided insightful responses. In support of the analysis, it would have been beneficial to have one question on previous flooding experiences and changing the open question about when the first warning was received into a closed date/time question format.
- The disseminations strategy of using social media was quite successful and through specific groups it was easier to find motivated participants. However, it needs to be acknowledged that this strategy has certain biases. Firstly, the online and social media dissemination can cause the exclusion of the elderly who may not be technologically minded. Nonetheless, it shall be noted that it turned out that the age distribution was comparable to the German age structure (Statistisches Bundesamt, 2024), only the age group 25-54 years was minimally overrepresented. Secondly, using almost solely Facebook groups might have yield a bias on the personality of the participants as they may be more active and engaging then others. However, this cannot be proven due to the design questions.

4 Empirical Chapter I: Surprise Floods: The role of our imagination in preparing for disasters

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Abstract. What's the worst that could happen? After a flood has devastated communities, those affected, the news media, and the authorities often say that what happened was beyond our imagination. Imagination encompasses the picturing of a situation in our minds linked with the emotions that we connect to this situation. However, the role imagination actually plays in disasters remains unclear. In this regard, we analysed the responses of a survey that was disseminated in the 2021-flood-affected areas of Germany. Some respondents perceived that due to their lack of imagination regarding the flood, they did not take adequate action in advance. Limited or a lack of imagination could be linked to never having experienced a flood before, difficulties in interpreting forecasts and warnings, the perceived distance to waterbodies, and cognitive biases. Overall, the responses indicated the influence of imagination on risk perception. Based on these results, we recommend that future research should investigate the extent to which visual support can help forecast and warning communication to trigger the imagination of citizens in the short-term. From a long-term perspective, research should focus on how to cultivate imagination over time through participatory risk management, developing climate storylines, citizen weather observations, and the like.

Keywords: impact-based forecasting, flooding, virtual reality, climate storylines, early warning, communication

4.1 Introduction

Devastating floods around the world are often reported to as being “beyond our imagination” (ClimateChangePost, 2021; Dhakal, 2023; The News International, 2022; United Nations, 2023). In science communication and storytelling studies, this expression of something being beyond imagination is primarily used to highlight disasters for which the scale and the impacts are unknown, unexpected, or a complete surprise (Cologna et al., 2017; de Bruijn et al., 2022; Hollnagel & Fujita, 2013; Kundzewicz et al., 1999; Merz et al., 2015).

Despite the common use of the term imagination and the vast amount of literature in disciplines such as psychology, philosophy, and arts, the concept of imagination is not explored in depth in disaster research. However, our imagination (and its limits) plays an important part in preparing for uncertain futures through picturing threats and hence, perceiving risks as well as through the imagination of possible adaptations or disaster preparedness actions (Coeckelbergh, 2008; Coulter, 2018; Heino et al., 2022; Ponce de Leon, 2020). Imagination usually refers to our ability to visualise a situation in our mind (Finn et al., 2023). Besides picturing a situation and possible actions, imagination is closely linked to our senses and how we might feel in this situation while taking these actions (Nanay, 2016). This ability to travel through time, picture, and test various scenarios strengthens us in anticipating and planning our future (Taylor, 2011). We are living in a world where the future can turn into uncountable possible scenarios, and this makes us feel uncertain about our actual futures (Yusoff & Gabrys, 2011). Forecasts and warnings of severe weather aim to support us in grasping likely future scenarios, and there is an assumption that imagining these scenarios will make us take preparative actions. However, even if forecasts and warnings are received by citizens (and sometimes they are not), they may not trigger the imagination of the impacts of the severe weather, and this means that people may not prepare for them. An example of this are the floods in Germany in July 2021, when devastating deadly floods occurred in western Europe due to stagnating low pressure causing heavy rainfall of up to 180mm in 72h (Junghänel et al., 2021; Kreienkamp et al., 2021). The intense precipitation and resulting flooding were both forecasted in advance for Germany at the national as well as at the European level (Thieken et al., 2023). However, the flooding took thousands of people by surprise because many of them, foremost, did not receive any warnings, or perhaps more importantly, did not take the

forecast or warning seriously or could not understand or imagine the consequences of the forecasted flooding (Cloke, 2022; Fekete & Sandholz, 2021).

> *‚Es war klar, dass viel Regen kommt. Mir fehlte die Vorstellungskraft, was das bedeutet.‘*
> *(In English: ‘It was clear that a lot of rain was coming. I lacked the imagination of what that means.’)*
> *Survey participant from Bad Neuenahr-Ahrweiler*

If forecasts and warnings are not always effective and do not always steer people to be able to imagine and prepare for serious floods (de Bruijn et al., 2022; Thieken et al., 2023), then we need to understand why. To address this research gap, this study aims to explore the role imagination plays in preparing for floods based on the responses of a semi-structured online survey disseminated in areas affected by the 2021 flooding in Germany. As risk perception (the individual understanding and belief about a risk) is a well-known phenomenon influencing disaster preparedness behaviour (Bubeck, Botzen, & Aerts, 2012), this study seeks to gain firstly a better understanding of the connection between imagination and risk perception. Secondly, it aims to identify what limits the imagination of a hazard and how this affects the preparedness of citizens and thirdly, distil possibilities for improving the communication of risk and severe-weather forecasts and warnings to trigger and cultivate imagination in the future.

First, we frame the concept of imagination in Section 4.2. Then, we present the case study, the online survey, and its analysis in Section 4.3, and the results in Section 4.4. The main outcomes of the study are concluded in Section 4.5.

4.2 Imagination

What is imagination? In the context of this study, it can be described as the ability to depict a particular situation in your mind and your actions linked to that situation (Nanay, 2016). An example is, depicting river floodwater rushing into your basement and consequently evacuating yourself and your family to safety upstairs. Imagination also encompasses the emotions that this depiction of a flood might raise in us (Nanay, 2016), like worries about the valuable things being flooded in your basement or the fear of not knowing how high the water will rise and whether you and your family will be safe

on the second floor. You yourself might have just been imagining this flood as you read this paragraph.

Creating these kinds of images in our mind is a cognitive ability and process that we commonly apply and refer to as imagination (Finn et al., 2023). We use our imagination in our daily lives, especially in decision-making. We tend to select the options that have a positive outcome, are not costly, are within our (perceived) abilities, and that might even have additional benefits for us (Heidenreich et al., 2020; Kuhlicke, Seebauer, et al., 2020; Sunderrajan & Albarracín, 2021; Wang et al., 2021). This method of decision-making exemplifies more controlled or rational behaviour compared to a decision made in panic (Sunderrajan & Albarracín, 2021).

We draw on imagination voluntarily to try to depict how an episode of the future might look (de Vito & Della Sala, 2011). You may not imagine several days of flooding and everything that might happen during those days but rather a moment such as sitting on your roof, crying, and waiting for help. However, imagining exactly this episode might be building on previous experiences that pop up as mental imagery in your mind (Nanay, 2021). Our imagination may draw on previous flooding experiences (if there are any) but is not confined to them (Finn et al., 2023). Thus, mental imagery can support us in creating images of potential futures in our mind (Cavedon-Taylor, 2021).

4.2.1 What shapes our imagination?

The way we imagine is not only shaped by our ability to imagine but also by external and internal influences. Commonly, we develop our ability to imagine from early childhood (Taylor, 2011). While every person may have different abilities, extreme forms of imagination exist, and some people have a very vivid imagination, which is known as hyperphantasia, while others may not have any imagination at all (aphantasia; Palermo et al., 2022).

External influences can shape our imagination, which has been increasingly explored in research on imaginaries. For instance, geographical “imaginaries” explain that our imagination is shaped by spatial aspects i.e., how we think and feel about a place (Walshe et al., 2023). This concept can be further extended to controversial discussions around the influence of the proximity to a risk area on risk perception (Ali et al., 2022; O’Neill et al., 2016; Rana et al., 2020). For instance, do people living next to a river have a higher risk perception than people living far away from it?

Our imagination can be directed by personal factors. For instance, for some people, the trauma caused by past flood experiences can restrict their ability to picture the future in their minds (Gotlib, 2021). While for other people, the experience of previous floods can cause future threats to repeatedly reappear in their imaginations, resulting in hyper-vigilance (Mehring et al., 2023). Imagination as a cognitive ability can also be hampered by wishful thinking, the attribution of reality to what one wishes to be true, even though it is not likely: for instance, when we think nothing bad will happen to us because floods are not things that are likely to happen, and everything will be alright. Imagination can also be restricted by the availability bias: for example, when we draw on our recent flood experiences and assume all future floods will be exactly like those (Merz et al., 2015). In reality, different floods can be very different experiences indeed. We usually overestimate the risk of potential future flooding if we have experience of previous floods, while we underestimate the risk if we have no experience (Fischhoff et al., 1982; Nanay, 2016).

4.2.2 Imagination and risk perception

Imagination is rarely discussed directly in disaster research. However, risk perception is a closely linked concept, which refers to our belief about the potential risk from a flood (Bulley & Schacter, 2021; de Guttry & Ratter, 2022). At first glance, imagination and risk perception may seem interchangeable, but in fact imagination plays a part in our (flood) risk perception (Bulley & Schacter, 2021). It is acknowledged that risk perception is primarily influenced by reality and our factual knowledge, such as locations of areas of flood risk, while imagination takes risk perception much further by adding the mental picturing of a flood and the emotional component (the feelings that may be triggered by this mental picturing; Karlsson et al., 2023; Sobkow et al., 2016).

Risk perception may be lower if the imaginative part is not triggered: for instance, if listening to or watching weather forecasts does not result in a mental depiction of the hazardous impacts. Although some weather forecasts and warnings now explicitly try to communicate impact (Potter et al., 2018; Speight et al., 2021), this is far from universal and most weather forecasts and warnings around the world still present information in a meteorological-fact-driven way: for example 40mm rain in an hour, or a rise in the river of 1m in 1 day (WMO, 2015). This is despite the WMO calling for the

global implementation of impact-based forecasting and warning (WMO, 2015). The difficulties in translating what might seem like an arbitrary amount of rainfall into a mental picture (and potential emotions), may lead us to perceive a lower risk. As we have seen, this translation could be affected by a lack of knowledge or experience but also by cognitive biases or obstacles such as trauma. However, in some cases past flooding experiences can benefit both sides of risk perception – the factual and the imaginational – through knowledge gained and mental imagery, respectively.

Risk perception is a prominent factor used to explain individual actions and motivations for preparing for flooding (Bubeck et al., 2013; Felletti & Paglieri, 2019). Although risk perception is not the sole factor prompting preparedness actions (Bubeck, Botzen, & Aerts, 2012; Lindell & Perry, 2012), it can lead to inaction if flood risk is perceived to be low (Kox et al., 2015). Nonetheless, even if we perceive that there is a risk of a severe flood, it does not automatically trigger us to act (Bubeck, Botzen, & Aerts, 2012; Kuhlicke, Seebauer, et al., 2020). For instance, we might perceive the flooding to be so severe that we believe our abilities are not enough to take any or sufficient action, i.e. action is pointless because the outcome will be the same; disastrous.

4.2.3 Triggering and cultivating imagination

Considering that our imagination can influence our flood preparedness behaviour, how exactly might this occur? Using photos of previous floods is known to be one effective strategy for communicating warnings, especially if these photos are from areas near where the people receiving the warnings (Kuller et al., 2021). As we have seen, impact-based forecasting aims to depict the potential impact of an approaching flood and the implementation of such an approach was strongly recommended after the 2021 floods in Germany (Apel et al., 2022). Seeing the potential extent of the floods, the impact on maps, or similar methods of visualisation may help us in creating mental images of potential flooding and may increase the uptake of disaster preparedness actions. This digital visual support is further explored with tools such as virtual and augmented reality or digital twins (Bakhtiari et al., 2024; Mol et al., 2022; Skinner, 2020).

As we have seen, imagination is known to develop over time throughout our childhood and daily life, therefore, it is more commonly researched from a long-term perspective

(Dobraszczyk, 2017; Finn et al., 2023; Higueras & Molina Villaverde, 2022; Taylor, 2011). In particular, disaster imagination can be cultivated through future visioning workshops (Nalau & Cobb, 2022), perhaps linked to risk communication approaches (Balog-Way et al., 2020; Kellens et al., 2013). In addition, longer-term interactions with people and drawing on approaches from the arts such as storytelling, narratives, or simulations can be used for risk communication, understanding problems (i.e. flood risk areas), and identifying solutions for them (Bø & Wolff, 2020; Fleming et al., 2016; Lloyd Williams et al., 2017). An example of this is the adoption of storytelling in the climate storyline approach which builds on the unfolding of previous disasters or potential futures (Shepherd et al., 2018). Moreover, combining the arts and humanities to create multi- and trans-media tools for i.e. reviving historic events and people's memory of these or enhancing intergenerational hazard knowledge sharing can foster an emotional response and mental picturing (Sevilla et al., 2023).

Throughout this section, we conceptualise imagination as the ability to create mental pictures of situations and potential actions while also attempting to feel what we would feel if the situation were reality. Our imagination can be supported by past experiences visually stored in our memory, but it can also be influenced by different factors. This section has highlighted the close relationship between imagination and our risk perception and the question of whether imagination can be triggered by receiving weather forecasts and warnings to increase preparedness motivation. The triggering of imagination could also be done with visualisations such as photos or videos and can also be cultivated over time, for instance, through storytelling approaches.

4.3 Methods

4.3.1 Case study: July 2021 flooding in Germany

In July 2021, severe rainfall stagnated over western Europe (Germany, Belgium, the Netherlands, France, and Luxembourg) for several days. This followed a longer wet episode in the summer. In Germany, the two states of Rhineland Palatinate (RLP) and North Rhine-Westphalia (NRW) were primarily affected with up to 182mm of rainfall recorded in 72h (Junghänel et al., 2021). Due to the saturated soil, the water could barely infiltrate into the ground (Kreienkamp et al., 2021). Especially, in hilly regions,

surface runoff led to flooding, landslides, and other hazards (Dietze et al., 2022; Ibebuchi, 2022; Lemnitzer et al., 2021). Different types of flooding occurred throughout the states: flash flooding in smaller hilly catchments, fluvial flooding of rivers and streams, and pluvial flooding partly forming gullies and new streams (Dietze et al., 2022; Thieken et al., 2023).

The event turned into a devastating disaster. In total, it was estimated that 162km^2 was flooded of which 35.6% was in built-up areas (He et al., 2022). The (flash) flooding took many people by surprise; more than 180 people lost their lives and more than 760 were injured throughout RP and NRW (Lehmkuhl et al., 2022; Thieken et al., 2023).

The communication of forecasts and the dissemination of warnings was one major issue leading to the high impact of the disaster. The heavy rainfall and likely flooding extent were forecasted in advance through the European Flood Awareness System (EFAS) and German Weather Service (Deutscher Wetterdienst; Thieken et al., 2023). However, the trickling down of the information from the forecasts to those who needed it on the ground encountered many obstacles: power outages and a lack of emergency sirens (Kuehne et al., 2021); missing information, missing behaviour recommendations, and misinformation (Fekete & Sandholz, 2021); or underestimation of the severity of the flooding by authorities and the public (Thieken et al., 2023).

4.3.2 Online survey

To gain a better understanding of the perspective of citizens affected by the floods, an online survey was designed. The online survey allowed collection of responses over a large area. The survey was primarily designed for flood-affected citizens 18 years of age and older who lived in North Rhine-Westphalia and Rhineland Palatinate during the time of the flooding (Figure 6). These two federal states were selected because they were most severely impacted by the floods in Germany. The survey was developed in both German and English and approved by the ethical committee of the University of Reading (14th February 2022). Following approval, it was disseminated via social media channels (Facebook, Twitter, LinkedIn, and WhatsApp) between March and July 2022 – less than 1 year after the event. The authors were aware of potential biases, i.e. the age structure of respondents due to the chosen social media dissemination strategy.

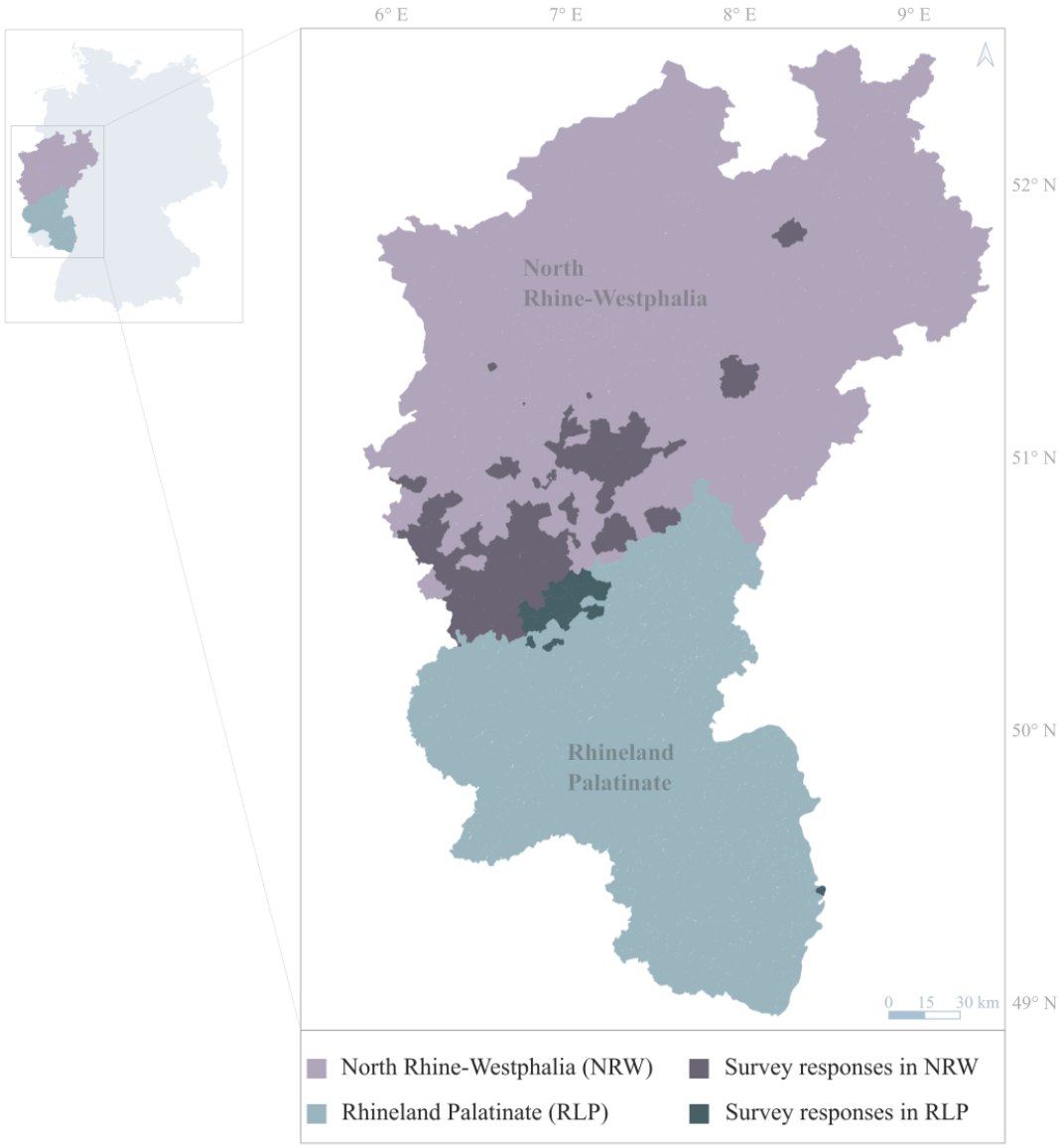

Figure 6. The study area in Germany covering the states of North Rhine-Westphalia (NRW) and Rhineland Palatinate (RLP) and the specific areas from which survey responses were received

The survey (available in Appendix 1-2) included mainly open questions in order to give the affected citizens a voice. Closed questions were only used in cases such as the collection of basic information or when information was clearly definable like the source of flooding. The questions addressed the following topics: the flooding source, risk awareness, preparedness, response, early warning dissemination and content, issues that arose and solutions for the future, perception of roles and responsibilities, and basic questions (age, living situation, and postcode). Since the survey was primarily designed to gain an insight into early warning, preparedness, and response and the topic of imagination only emerged from this survey, the analysis of the results faced several limitations which, in some cases, prevented deeper insight into the reasoning behind a finding.

4.3.3 Data analysis

After preprocessing the data (translation and post code correction), the responses were analysed through descriptive statistics and thematic analysis. Descriptive statistics were used to gain a quantitative understanding of actions. The thematic analysis (Braun & Clarke, 2006) was applied to gain a deeper insight into the responses but primarily to distil overarching themes that arose throughout several questions, especially throughout the open questions. The thematic analysis aims to work across multiple questions instead of analysing the responses to one question in isolation. This method was chosen to identify patterns and important themes that citizens have pointed out within their responses. The analysis includes four steps: 1) familiarisation with the collected responses, 2) initial coding in NVivo (release 1.7.1) and Microsoft Excel, 3) identification of themes, and 4) the distilling of overarching themes such as imagination in this case. The overarching theme of imagination emerged from coding responses in NVivo while the sub-themes discussed in Section 4.4 were identified by manually coding imagination-related responses in Microsoft Excel.

4.3.4 Responses

The survey received 438 responses, of which four were written in English and 434 in German. The survey responses were filled in anonymously and the postcodes were aggregated to the municipality level to maintain participant anonymity. The majority (87.7%) of respondents lived in NRW and 12.3% lived in RP (Figure 6). Thus, 116 responses were collected in the district of Kreis Euskirchen, 73 in Städteregion Aachen, 61 in Rhein-Sieg-Kreis, 48 in Landkreis Ahrweiler, and 42 in Rheinisch-Bergischer Kreis. Further districts were represented by 30 or fewer responses. The respondents covered all age groups (18 years and above) that were invited to contribute. Here, 65% of the participants were between 25 and 54 years old, which slightly over-represents this age group compared to German demographics (Statistisches Bundesamt, 2024). Even though, the survey was in an online format, it did not prevent older age groups (65+) from contributing (9%). About 6% of the participants were between 18 and 24 years old, and 19% were between 55 and 64 years old.

Almost all (96%) survey participants experienced flooding either directly or indirectly (e.g. through family, neighbours, and friends). The flooding was rated as extreme by

75% of the participants. More than half stated that they were directly affected by the flooding, and 250 people ticked that their family, friends, or neighbours were affected. The businesses of 44 participants were flooded, and 262 respondents indicated that their daily life was affected by the flooding. Overall, three-quarters of the respondents selected (from predefined options) that they experienced extreme flooding, 19% declared that the flooding was worse than usual, 3% were affected by light or the usual flooding, and 1% did not experience any flooding.

4.4 Results and discussion

The theme of imagination appeared in a number of different ways in the survey responses, revealing challenges in imagining extreme flooding and allowing us to explore the connection between imagination and risk perception as well as disaster preparedness, and finally, highlighting enablers of and barriers to imagination.

4.4.1 Imagining an unexperienced severe hazard

Imagining the flood was largely determined by previous experiences, which is also an important factor shaping personal risk perception. In particular, the severity of a previous hazard was found to play a role in risk perception (Bubeck et al., 2012). The results of this study indicated that drawing on their mental imagery (from previous experiences), participants could imagine the approaching hazard better but only up to the hazard extent of the previous time. Overall, the severity of the hazard was often linked with the limitations of imagining the hazard as it turned out to be beyond imagination. In particular, it was mentioned that the extent or dimensions of the flooding was unimaginable.

> '*Das Ausmaß könnte sich niemand vorstellen.' (In English: 'No one could imagine the extent.') (Bonn)*

More specifically, the severity of the flood was not imaginable because the characteristics of the hazard, such as the depth, speed, and power of the water had not previously been experienced. For example, many people have not had the previous experience of walking through flood water.

> *'[...] weil ich definitiv keine Vorstellung davon hatte, wie gewaltig Wasser sein kann.' (In English: '[...] because I definitely had no imagination of how powerful water can be.') (Odenthal)*

Overall, the 'unknown' emerged as a prominent factor in people's experiences of the flood, and this points to the limitations of our imagination, especially, in the context of previous flooding experiences. The unknown (the never experienced or expected) is what is often describe in the news as 'beyond our imagination' (ClimateChangePost, 2021; Dhakal, 2023; The News International, 2022; United Nations, 2023; WDR Doku, 2022) which is also referred to as a surprise once it occurs (Merz et al., 2015). Hence, something unknown challenges our abilities to imagine.

> *'Die Wassermassen kannten wir nicht und waren bis dahin unvorstellbar' (In English: 'We were not familiar with the masses of water, and until then, they were unimaginable.') (Aachen)*

Interestingly, even previous experiences of floods can limit our imagination, as survey participants showed that they could not imagine anything greater than what they were used to. This finding could be related to the claim that our imagination is limited through routines (Higueras & Molina Villaverde, 2022); thus, if a certain level of flooding is experienced a few times, then imagining that it could be more severe is very difficult.

> *'Weil Überschwemmungen hier in der Vergangenheit nicht so schlimm waren und ich nicht damit gerechnet habe, dass das Wasser diesmal bedeutend höher steigt.' (In English: 'Because flooding here hasn't been that bad in the past and I didn't expect the water to rise significantly higher this time.') (Aachen)*

4.4.2 Imagination and risk perception

In many responses, it is difficult to distinguish between imagination and risk perception, but in the following statement, the person clearly expressed the fact that

the personal underestimation of risk was also influenced by how unimaginable the flood was (Bulley & Schacter, 2021; de Guttry & Ratter, 2022).

> *'Das Ausmaß der Katastrophe bis zum Schluss unterschätzt - es war im wahrsten (!) Sinne des Wortes UNGLAUBLICH und UNVORSTELLBAR!' (In English: 'The extent of the catastrophe underestimated until the end - it was literally (!) UNBELIEVABLE and UNIMAGINABLE!') (Bad Neuenahr-Ahrweiler)*

Place. Several respondents could not believe that they would be affected by the flooding, and this indicates that they perceived that there was no risk. In many of these cases, this was because of the location of their homes. For instance, they were far away from any flowing water or was even on a slope; thus, the respondents did not expect to be flooded. This proximity or distance to a risk area is commonly known as an influencing factor for risk perception, but the way in which it influences is not agreed on as studies show varying results (Ali et al., 2022; O'Neill et al., 2016; Rana et al., 2020). Our results show that the distance to water and living on slope were often linked to lower perceived risk.

> *'Ich dachte nicht, dass es uns erreichen könnte, da der Bach eigentlich weit weg ist.' (In English: 'I didn't think it could reach us as the stream is actually far away.') (Weilerwist)*

This lower perceived risk due to distance was related to past experiences where the flood did not reach their homes. Thus, they did not expect to be affected now. Here, past experiences probably influenced the belief about these places, and this connects to the concept of geographical imaginaries in which we have a certain idea or perspective about the places around our homes that has evolved over time (Walshe et al., 2023).

Availability bias. As we have seen, previous flooding experiences are known to influence risk perception, and people cannot imagine anything greater than they have seen before. Expanding upon this finding shows that by drawing on their experiences, a false assessment of risk was estimated by respondents.

> *'Die Reaktionszeit war gleich Null, da wir in unserer Gegend nicht mit einer solchen Flutwelle gerechnet hatten.*
> *Beim Hochwasser 2016 waren wir überhaupt nicht betroffen.' (In English: 'The reaction time was zero because we did not expect such a flood wave in our area. We were not affected at all during the flood in 2016.') (Bad Neuenahr-Ahrweiler)*

Here, people are using their most recent experiences. In this example, this was the flooding in 2016, which was announced as one of the most severe floods of the Ahr River (Piper et al., 2016). Using past experiences in this way and gaining some knowledge about flood behaviour can therefore also turn into a cognitive bias, the availability bias, limiting the imagination of a potentially more severe event (Merz et al., 2015). This further relates to the mental imagery that helped to imagine the flooding as it was in 2016 but nothing beyond that.

Wishful thinking. Another cognitive bias that arose from the responses is wishful thinking. As we have seen, wishful thinking describes a cognitive bias in the belief that nothing significant will happen even though a person may even expect that flooding will actually happen (Merz et al., 2015). We find that respondents could not believe that something significant would happen and held onto the belief that all would be fine.

> *'Ich konnte es wie so viele nicht glauben. Ich habe mir die ganze Zeit gesagt es hört jetzt auf zu regnen und die Ahr geht wieder zurück.' (In English: 'Like so many people, I couldn't believe it. I kept telling myself it would stop raining and the Ahr would go back again.') (Bad Neuenahr-Ahrweiler)*

Interestingly, this quote perhaps implies that the person actually imagined what could happen and, therefore, had the hope that it would not happen and was deliberately blinding themself to the risk. Additionally, this person shows an emotional aspect, namely fear, which is likely to have increased the wishful thinking. However, more investigation is needed to understand to what extent and in which ways this person actually imagined what could happen.

Flood mitigation measures. Another interesting finding that can be linked to previous flooding and risk perception is expressed in the following quote:

> *'Unser Haus ist auf einem Sockel gebaut, der die letzte Flut aus den 80er Jahren berücksichtigt hat. Wir dachten, das würde reichen' (In English: Our house is built on a pedestal that took into account the last flood from the 1980s. We thought that would be enough.') (Aachen)*

The respondent mentions that the house was built in a way that it would be flood resistant because it was elevated. Therefore, it would be safe if it flooded in a similar way as the flood in the 1980s. However, this knowledge and sense of security that the house would be safe in case of a flood may have limited their imagination that the flooding could be worse and that the water depth could be even greater. This is another example of where the flooding could be characterised as beyond imagination or was it rather beyond experience? This respondent may not have experienced the flooding in the 1980s firsthand but still had the knowledge about the potential water depth. This water depth was possible to imagine for this person. Hence, it shows that imagination does not exclusively build on previous experiences and mental imagery.

4.4.3 Imagination and preparedness

Limited imagination of the approaching threat was found to be one influential factor for inaction. A few people still took actions, often because of their previous flooding experiences and therefore higher perceived risk. However, the people who prepared for the event mainly focused on last-minute emergency measures.

Inaction. The difficulties of imagining the threat itself can potentially be linked to inaction. Several people who expressed that they could not imagine or realise the extent of the threat, mentioned that they did not prepare.

> *'Ich war auf diese Wassereinbrüche nicht vorbereitet, weil ich definitiv keine Vorstellung davon hatte [...]' (In English: 'I was not prepared for these water intrusions because I definitely could not imagine it[...]') (Odenthal)*

> *‘Keiner war vorbereitet! Bzw. hat das Ausmaß nicht realisiert.’ (In English: ‘No one was prepared! Or rather, did not realise the extent of it.’) (Bad Münstereifel)*

The term ‘realise’ implies the idea of making something real which can be closely linked to picturing the threat. The following quote highlights that the rainfall forecasts received could probably not be imagined because the person was lacking knowledge or experience to translate this factual information into mental images.

> *‘Die angegebenen [Regen] Mengen pro Quadratmeter waren nicht richtig zu begreifen oder zu fassen. Ich hatte keinerlei spezielle Vorkehrungen getroffen.’ (In English: ‘The stated quantities [of rainfall] per square metre could not be understood or grasped correctly. I hadn't taken any special actions.') (Euskirchen)*

Some responses showed that people might have imagined the threat but could not imagine any actions they could take because the threat seemed much greater than their own abilities. This links directly to the behavioural protection motivation theory, which states that people are motivated to protect themselves and their families based on both the personal threat that they perceive and their appraisal of their own abilities to take action - their belief in what they are able to actually do (Bubeck, Botzen, & Aerts, 2012; Kuhlicke, Seebauer, et al., 2020). In the following quotes, the belief of being powerless is described, and this could express that people did not believe that their abilities were sufficient, or the flood was perceived to be too severe.

> *‘Da kann man leider nichts tun, Man ist machtlos. […] Man handelt irrational.’ (In English: 'Unfortunately there's nothing you can do, you're powerless. […] You act irrationally.') (Zülpich)*

After experiencing this severe flooding, some people still could not imagine any actions that they would be capable of taking to be prepared in the future.

> *'[...] weil man sich da auch in Zukunft nicht drauf vorbereiten kann. Außer wegziehen.' (In English: '[...] because you can't prepare for it in the future either. Except move away.') (Landkreis Vulkaneifel)*

One respondent mentioned that, especially after this severe flooding, it would be impossible to imagine actions in case of an even worse flood.

> *'Sobald jedoch mehr Infrastruktur beschädigt worden wäre, ist es immer noch schwer vorstellbar, was wir tun sollten.' (In English: 'However, once more infrastructure had been damaged, it is still difficult to imagine what we should do.') (Dahlem)*

Not knowing or imagining potential actions in preparedness or response led to irrational actions; thus, the ability to imagine possible worst cases and actions that could be performed is important and therefore, needs to be communicated well, planned, and trained for.

> *'Klare Vorgaben für alle, es muss die Überlegung geben, dass so etwas passieren kann, dieses Ereignis war so nicht vorstellbar und war auch nie trainiert worden.' (In English: 'Clear guidelines for everyone, there must be consideration that something like this can happen, this event was unimaginable and had never been trained.') (Zülpich)*

Action. In contrast to the above, some respondents actually took actions despite the fact that they mentioned they could not imagine the threat. These actions were primarily emergency measures, and this may imply that the respondents at some point realised the approaching flood.

> *'Meiner Familie geholfen [...]. Sandsäcke befüllt, Unterlagen gesichert.' (In English: 'Helped my family [...]. Sandbags filled; documents secured.') (Bad Neuenahr-Ahrweiler)*

> *‘Pumpen im Keller installiert; Autos in einer höher gelegenen Region geparkt.’ (In English: ‘Pumps installed in the basement; cars parked in a higher area.’) (Aachen)*

> *‘Außenanlagen gesichert.’ (In English: ‘Outdoor facilities secured.’) (Euskirchen)*

Another reason that people prepared despite not being able to imagine the hazard extent can be explained by previous experiences and linked availability bias. These people have experienced flooding once or several times before and were familiar with it; thus, they prepared routinely.

> *‘Die von vorherigen Starkregen-Ereignissen bekannten Schwachstellen gesichert. War leider nicht ausreichend, da die Regenmenge zu viel war.’ (In English: ‘The vulnerabilities known from previous heavy rain events have been secured. Unfortunately, it wasn't enough because the amount of rain was too much.') (Aachen)*

> *‘Ich habe schon oft Hochwasser in diesem Haus erlebt, so dass ich eine gewisse Routine und Gelassenheit bewahren konnte. […] So extrem kannte ich das dann doch noch nicht.’ (In English: ‘I have experienced flooding in this house many times, so I have been able to maintain a certain routine and composure. […] but this extreme was unknown to me.’) (Sudern)*

Interestingly, this routine of preparing for floods demonstrated rational and calm behaviour; they knew what they had to do. We have seen that previous experience limits the imagination of something more severe than the usual flooding, and here this shows the same effect but going one step further: the people prepared as they usually did but since they could not imagine something more severe, they also did not prepare for a more severe event. They stayed in their familiar preparedness routine. This was on the one hand very useful, but on the other hand, the routine became a trap that limited imagination. Routines are known to be the enemy of imagination as they restrict thinking and imagination beyond the usual habits (Higueras & Molina Villaverde, 2022).

4.4.4 Triggering and cultivating imagination

The previous sections highlighted the linkage between risk perception and imagination and the importance of their interplay for taking preparedness actions. Furthermore, these sections underlined the need to increase imagination of severe hazards. Hence, in this section, we explore to what extent weather forecasts and warnings (if received) could trigger imagination (or not). In addition, we are discussing how disaster imagination could be cultivated over a longer time period.

Triggering imagination through weather forecast and warning (short-term). The forecasts and warnings about heavy rainfall and potential flooding were not always understood in the way that was expected by forecasters. This is not an uncommon reality since risk communication varies and messages can be differently understood and acted upon (Parker et al., 2009). Linking this to imagination, some respondents stated that hearing about the amount of projected rainfall did not trigger their imagination of what was about to happen.

> *'Ich wusste das es viel regnen soll, konnte mir bei der Liter Angabe aber nicht drunter vorstellen, dass es SO viel sein würde…' (In English: 'I knew it was going to rain a lot, but given the litres I couldn't imagine that it would be THAT much…') (Erftstadt)*

Thus, hearing a certain number or seeing a purple-coloured warning was mentioned to be too abstract or vague to create an image in one's mind, i.e. picturing how this number would change the water level. However, it remains unknown whether a water level would actually be useful for triggering imagination considering that the forecasted rainfall amount was claimed to be too abstract.

> *'[…] die genannten Regenmengen von "bis zu 100l/m²" sind zu abstrakt […].' (In English: '[…] the mentioned rainfall amounts of "up to 100l/m²" are too abstract […].') (Aachen)*
>
> *'Die Markierung auf der Wetterkarte war tieflila. Sagt aber nichts über die Höhe des evtl. Wasserstandes aus.' (In English: 'The marker on the weather map was deep purple. But it says nothing about the height of the possible water level.') (Bad Neuenahr-Ahrweiler)*

Imagining a situation can be easier if people are able to draw on their mental imagery, for instance, if people have experienced flooding before. Survey participants reported that receiving photos or videos of the flooding from friends or family helped them to picture what was happening, and this potentially helped them to imagine what may have been about to happen in their own localities:

> *'[...] bewusst wurde es erst durch die Bilder aus Hagen.' (In English: '[...] I only became aware of it through the pictures from Hagen.') (Euskirchen)*
>
> *'20:45 Video von Altenahr erhalten und von dann das Wasser nicht aus den Augen gelassen.' (In English: '20:45 video received from Altenahr and from then on I didn't take my eyes off the water.') (Dernau)*

In this example, the video was from an upstream location only about 7.5km away. Hence, through watching the video, it was clear that this situation was real and was very likely to happen soon in the respondent's village. The spatial proximity of a source of information is known to be an effective way to trigger an alerting effect in people's minds (Kuller et al., 2021). Additionally, if the photo or video presents a situation that is familiar to a person, it can trigger the emotional aspect of imagination:

> *'Ich erhielt ein kleines Video von einem Parkplatz, der unter Wasser stand. Dort setzte sich ein Auto in Bewegung, was mich schockierte, da ich mir das Entsetzen des Besitzers vorstellte.' (In English: 'I received a short video of a parking lot that was under water. A car started moving there, which shocked me as I imagined the owner's horror.') (Bad Münstereifel)*

Illustrating the potential impact seems to be an important element in triggering our imagination of the potential threats:

> *'Mehr darüber berichten und ggf. mal veranschaulichen, was es bedeutet, wenn 200l/qm runter kommen.' (In English: 'Report more about it and if necessary, illustrate what it means when 200l/sqm comes down') (Erftstadt)*

As we have seen, a starting point for integrating visuals can be impact-based forecasting (Potter et al., 2018) and using virtual or augmented reality (Bakhtiari et al., 2024; Mol et al., 2022).

Cultivating imagination (long-term). Working with visuals may be an effective way to enable us to imagine the threat of flooding, but this may not be enough. As we have seen, some people can draw on previous experiences (at least to some limited extent) that others do not have. The results discussed so far suggest that people need access to some factual knowledge and imagination to increase risk perception. Hence, a first step is to encourage people to learn more about rainfall amounts, flood levels, and how these relate to what happens in their own neighbourhoods.

> *'Weil ich mich mit den persönlichen Konsequenzen bis heute nicht konsequent auseinander gesetzt habe.' (In English: 'Because I haven't consistently dealt with the personal consequences to this day.') (Bad Neuenahr-Ahrweiler)*

It may also be important for people to be more attentive to their own environment, to observe the rain falling locally, and to understand how wet the landscape is. For instance, one person who experienced the flood now has developed their own rainfall threshold at which preparedness actions will be taken.

> *'Ich würde anhand der zu erwartenden Regenmenge entscheiden. Bei den Mengen des letzten Jahres würde ich vorab schon die Taschen sicherheitshalber packen und mein Umfeld warnen. Bei den üblichen Mengen (ca. 40l/m^2) bleibe ich gelassen.' (In English: 'I would decide based on the expected amount of rain. With the quantities of last year, I would already pack my bags as a precaution and warn my surroundings in advance. With the usual amounts (about 40l/m^2), I remain calm.') (Euskirchen)*

Although not everyone has experienced severe rainfall and flooding, through their own regular observations people can gain a better understanding of what a specific rainfall amount communicated in forecasts and warnings can mean in someone's area or in upstream areas. In addition, people living close to a river or stream could start observing water levels; by comparing the forecasted levels with how the river looks in

reality, they may gain a further understanding of what water level forecasts mean in reality.

> *'Prognosen zu Überschwemmungsgebieten und Pegelständen sind wichtig.' (In English: 'Forecasts of flood zones and water levels are important.') (Euskirchen)*

To communicate risks or the need for environmental awareness and observation in a community, approaches such as storytelling could be used to identify and communicate local risks, unfold past hazards, or identify potential solutions to minimise risk (Balog-Way et al., 2020; Bø & Wolff, 2020; Fleming et al., 2016; Kellens et al., 2013; Lloyd Williams et al., 2017). This could be combined with participatory development of local climate storylines (Shepherd et al., 2018), multimedia supported discussions on past events (Sevilla et al., 2023), or future visioning in general (Nalau & Cobb, 2022). This way, imagination could be cultivated over time.

The quotes in this subsection on cultivating imagination could apply to everyone, although logically younger people may benefit most as they may have less experience with extreme weather:

> *'... gerade junge Leute können sowas ja nicht einschätzen was normal ist und was nicht, da viele bestimmt*
> *nicht studieren wann wieviel Liter Regen runter kommt um dann so eine hohe Liter Angabe einschätzen zu können.' (In English: '... young people in particular cannot assess what is normal and what is not, as many certainly do not study when and how many litres of rain come down in order to be able to estimate such a high litre figure.') (Erfstadt)*

4.4.5 Limitations and implication for future research

This study provided insights into the role of imagination in disaster preparedness by analysing a semi-structured survey. The analysis faced a few limitations that we recommend be considered for future research. Firstly, the results of the survey sometimes provided limited evidence about which speculative interpretations were necessary; thus, those themes without fully comprehensive evidence – meaning that more contextual information regarding a response would have been needed to draw

direct connections to existing theories - should be explored in more depth in future studies. This refers to the influence of hazard knowledge on imagination or whether imagination of a hazard can lead to wishful thinking. Secondly, some survey respondents expressed their emotions directly in their responses, which could be partly linked to imagination. Since emotions are a primary part of imagination (Nanay, 2016), future studies should explore this in more detail. In this context, it is recommended to use further qualitative methods such as focus groups (Finn et al., 2023) or interviews (Walshe et al., 2023). Thirdly, linkages to the idea of place and especially the proximity to hazard areas were found. Future research should focus on the external influence that different kinds of imaginaries (social, political, historical, or climate change) have on the imagination of specific disasters as discussed in this paper. A final recommendation is to further investigate the relationship between forecast uncertainty and imagination.

4.5 Conclusion

The primary ambition of this paper was to explore the role of imagination in disaster preparedness, as the term imagination is commonly used by the media but has not been specifically researched in the context of disaster events. For this purpose, the paper builds on a survey that was disseminated in flood-affected areas in Germany in 2021. In this paper, imagination is defined as our ability to picture a scenario and potential actions in our mind as well as the emotional consequence of them. The survey results indicate the difficulties that people had in imagining a severe flood and the consequences of this were that they did not take preparedness actions. People's ability to imagine a severe hazard was mainly hampered because of an element of unknowing. In other words, survey participants showed difficulties imagining something they had not experienced before, such as the power and speed of flood water or the dimensions flooding that can have. While previous experiences were found to be beneficial for the imagination, it was also found to cause bias in some people, as respondents could not imagine something worse than what they had experienced so far; it was literally beyond imagination.

We find that imagination is closely linked to the concept of risk perception: the risk we perceive builds on our factual knowledge (gained through education or experience) and our imaginations. Hence, if we are not able to imagine a severe hazard, then most

likely our risk perception will be lower. Our results suggest that our factual knowledge is often needed as a base or input for imagination. For instance, when hearing specific rainfall forecasts, it may not trigger our imagination if we cannot build on our factual knowledge which provides us with an understanding of what 200mm of rainfall in 1 day means.

Additional barriers to imagining a (severe) flood were identified that are commonly linked to risk perception: firstly, the spatial distance to a river or the location of a house on a slope prevented respondents from imagining that the flood would reach their homes. Secondly, some respondents demonstrated a specific idea and belief about a place in which flooding was considered impossible. This finding links to the concept of geographical imaginaries. Thirdly, cognitive biases showed barriers to imagination such as wishful thinking (and desperate hope). Respondents believed that flooding would not happen, often against the evidence and even though it was sometimes perceived as very likely. Another cognitive bias that was implied was the availability bias, which is closely linked to previous experiences of flooding and probably constitutes one of the main thresholds for risk in people's minds. Here, people could neither believe nor imagine that a flood could be worse than one they had already experienced; thus, it is likely that they were trapped in their mental imagery of the past.

A key finding of this work is the linkage between people not taking preparedness actions and the fact that they could not imagine the flooding in advance, which probably lowered their risk perception. People who had experienced flooding before may have prepared - but mostly only for the flooding extent that they had previously experienced because they did not imagine that the flood could be worse.

This study showed that imagination of something unknown poses a great challenge to many people. Therefore, it is important that weather forecasts and warnings can trigger imagination, which can help people perceive risk and taking preparedness actions. More research is needed on the communication of risk to trigger imagination in the short-term and especially on the impacts of severe-weather forecast and warning using the support of visual elements such as photos and videos, but also digital tools like virtual and augmented reality. These can support efforts in implementing impact-based forecasting and increase understanding of the dimensions of an approaching flood. Our results show that locality is important, and photos of a person's hometown or somewhere close by will likely make imagination of

the flood easier. Furthermore, showing familiar elements, such as a car that might be floating away, can increase the understanding and imagination of what might be happening.

Finally, it is important to cultivate our imagination over time by continuously increasing our factual knowledge of risk. This can be supported using creative approaches such as storytelling, future visioning, or multimedia tools and arts. For instance, local climate storylines could be co-developed with communities by discussing local risks, past flooding events, and potential flood mitigation options.

In conclusion, this study explored the role of imagination in risk perception and disaster preparedness, highlighting the fact that the imagination of unknown severe weather can pose difficulties and, therefore, constrain disaster preparedness. To gain a deeper understanding of the barriers to and enablers of imagination and how imagination can be incorporated in weather forecast and warning communication, more interdisciplinary research is needed. Research on imagination has the potential to transform the way in which forecasts and warnings are received, understood, and acted upon. If we can harness our power of imagination to help us prepare better for disasters, then we can save lives in future disasters.

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5 Empirical Chapter II: Risk social contracts: exploring responsibilities through the lens of citizens affected by flooding in Germany in 2021

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Abstract. Citizen priorities, needs, and rights have been moving to the centre of 'good' risk management and governance in theory, but what is their role in practice? The disastrous impacts of the flooding event across western Europe in 2021 highlighted many gaps and challenges in flood risk governance (FRG) structures in Germany. To better understand these, this study explored responsibilities as perceived by citizens and compares these with legal-institutional social contracts. These perceptions of citizens were captured in an online survey in the affected regions. The results indicate that German FRG remains a predominantly top-down system with citizens being dependent on the functioning of the risk and emergency system. The results of the survey highlight the need for: 1) clarifying and co-defining roles and responsibilities in FRG and making them more transparent; 2) enhancing citizen active involvement in governance and deliberating interactions; 3) rebuilding trust; and 4) creating joint responsibilities between citizens and local authorities. Based on the findings of the study, it became apparent that research on citizen centred FRG is steps ahead of policy and practice. To enhance policy and practice, recommendations were developed to foster collaboration between citizens and local authorities to strengthen local FRG.

Key words: Flood risk management; Flood risk governance; Decentralisation; Citizen engagement; Trust; Joint responsibilities; Shared responsibilities; Collective governance

5.1 Introduction

The importance of citizen involvement in flood risk management and governance has been emphasised globally throughout the past decades, mirroring a broader localisation agenda within the resilience discourse. This shift away from a solely top-down management is supported by research (Matczak & Hegger, 2020), global policies (i.e., Sendai Framework (2015)), and at European level (EU Floods Directive 2007/60/EC), but also emerged as a lesson learnt from flooding events (Platt et al., 2020; Puzyreva et al., 2022). People or human-centred approaches to flood risk governance aim at complementing the top-down approach with a bottom-up initiative, moving towards decentralisation and sharing responsibilities (Dordi et al., 2022; Matczak & Hegger, 2020).

In Germany, flood risk governance – the distribution of roles and responsibilities - is rooted in a top-down system which is increasingly decentralised, with responsibilities allocated to the federal states and municipalities (Snel et al., 2022). The responsibilities of citizens, meanwhile, lie predominantly in the protection and flood damage prevention of their own private property. The law generally positions German citizens as receivers, without space for local agency or voice in active decision-making for flood risk management. The disastrous flooding event in Germany in July 2021 highlighted an underlying dependency of the general public on the 'emergency system', and also demonstrated the 'expectations of the public for a perfect system' (Fekete & Sandholz, 2021). Building upon these findings, this paper aims to gain a deeper understanding on the distribution of responsibilities as citizens perceive how they are.

From a policy perspective, the empowerment of citizens and communities through increasing engagement and responsibilities was already set as one of the principles of the Sendai Framework to build resilience and reduce disaster risk. In theory, the decentralisation in flood risk governance can foster the active involvement of the general public (Mees et al., 2018; Renn, 2015; Rumbach, 2016) which can widen citizens' risk knowledge and have positive impacts on their own resilience (and vice versa) (Puzyreva et al., 2022). Active involvement refers to public participation going beyond traditional consultations by, for instance, encouraging engagement in local actions (e.g., implementing flood mitigation measures), contributions in planning as well as in discussions around local problems and solutions (Evers, 2012). The

involvement of citizens is of immense value for understanding local needs (Chambers, 1983), reducing potentially clashing expectations (Renn, 2015), and empowering citizens (Fekete & Sandholz, 2021). On the other hand, the willingness of citizens to get involved in governance may be limited due to the fact that citizens may not wish to gain more responsibilities that need to be realised and fulfilled (Snel et al., 2022), and there are a range of power dynamics and contextual social, political, economic, and other factors that either lower or enhance the participation of particular groups over others (Cooke & Kothari, 2001). Hence, further research is required on the extent to which German citizens feel willing and able to participate in flood governance, within their legislated role in current flood risk legal-institutional frameworks.

At present, German legislation does not explicitly facilitate a multi-directional interaction between citizens and local authorities, although recent policy developments are moving in this direction: the freshly drafted climate adaptation law at federal level (Bundes-Klimaanpassungsgesetz (KAnG) (draft version of August 2023)) does not ascribe any obligations to citizens but supports the engagement of the general public in the setting of local goals and selecting measures to achieve these. Similarly, the federal resilience strategy (Deutsche Strategie zur Stärkung der Resilienz gegenüber Katastrophen (2022)) - the national adoption of the Sendai Framework - enhances the joint action which refers to multi-level and multi-sectoral dialogues and collaboration also including representative groups of the civil society. However, the engagement recommendations remain, in both, at a superficial level without concrete or practical application guidance.

In accordance with the motivation of the resilience strategy learning from past and on-going disasters to identify needs and ways forward to increase the resilience in Germany, this study aimed to explore flood risk governance during the 2021 flooding from the lens of citizens because previous studies indicated a great dependence of citizen on authorities (Fekete & Sandholz, 2021). Therefore, this study strived to explore flood risk management responsibilities as perceived and understood by citizens to identify potential gaps between 1) their perception of responsibilities in flood risk management and 2) the roles or responsibilities assigned to different actors via the legal-institutional discourse and policy instruments. Furthermore, it explores local willingness and felt agency to participate in flood management, and whether this correlates to gaps in expected responsibilities.

For this purpose, this paper draws on 'social contracts' (Blackburn & Pelling, 2018) as a conceptual framework to explore the relations of trust and expectation between citizens and flood risk governance actors. The paper responds to calls for an expanded evidence base of how these *risk social contracts* are shaped by and operate within particular risk governance structures. To this end, an online survey was disseminated to capture citizens' understanding and expectations of responsibilities in risk governance as well as interactions between different actors. This study does not seek to allocate blame for the disastrous event, but rather aims to identify gaps in perceived or expected responsibility and understand how these arise, and hence to derive ways forward from the flooding experiences in 2021. To achieve this goal, themes around governance raised by citizens were distilled, analysed, and transformed into recommendations to support policy design and strengthen local risk governance in practice.

The paper opens with the conceptualisation of flood risk governance and connected theories in Section 5.2. Section 5.3 introduces the case study in Germany and the online survey, while Section 5.4 presents the results of the thematic analysis which are discussed in Section 5.5. Based on the discussion, Section 5.5.1 and 5.5.2 highlight key contributions and develop recommendations for policy and practice, respectively. Section 5.6 summarises the main outcomes of this study.

5.2 Flood risk governance

In this paper, the term flood risk governance (FRG) refers to the division and allocation of roles and responsibilities in flood risk management, and to the landscape of regulations and resources within which flood events are managed (Hegger et al., 2014). Governance encompasses decision and policy-making processes around flood risk management (FRM) (Renn et al., 2011), and aims 'to ensure the implementation of flood risk management strategies [through] a good organization' (Raadgever et al., 2018) while assuring 'accountability, participation, predictability and transparency' (Ahrens & Rudolph, 2006).

5.2.1 Decentralisation of responsibilities

Mainstream discourse on 'good' governance has encouraged the decentralisation of FRM roles and responsibilities to multiple public and private actors (Dordi et al., 2022; Matczak & Hegger, 2020) and idealises a 'non-hierarchical form of decision-making'

(Mees et al., 2016). In contrast to earlier times when flooding was managed by a single entity (Dordi et al., 2022), the decentralisation of FRG is now considered an important strategy of good governance due to the increased efficiency and democratic accountability it attempts to foster (i.e., decentralisation enhances knowledge sharing, cost reductions, the distribution of benefits, attuning to local contexts) (Bisaro et al., 2020; Matczak & Hegger, 2021). However, the organisation among multiple levels can hamper the success of FRG if roles and responsibilities are not clearly assigned, rules are not set, resources or channels for accountability are lacking (Bisaro et al., 2020; Blackburn, 2014; Dieperink et al., 2018; Hegger et al., 2014; Snel et al., 2022).

With the concept of shared responsibilities, citizens are gaining more responsibilities which commonly starts with redirecting the responsibility of protecting properties and houses to their owners (Henstra et al., 2019) which was also the case in Germany. Despite this ascribed responsibility, the number of people taking up this responsibility remains low due to the cost burden, lacking knowledge, awareness, support, or the realisation of own responsibilities (Bubeck, Botzen, & Aerts, 2012; Entorf & Jensen, 2020; Fekete & Sandholz, 2021; Henstra et al., 2019). As a result, whilst there is provision in the German FRM for decentralised activity, citizens largely remain dependent on the guidance of authorities (Fekete & Sandholz, 2021).

In contrast to the concept of shared responsibility, the concept of collective governance aims not at reallocating responsibilities but rather at establishing 'a governing arrangement where one or more public agencies directly engage non-state stakeholders in a collective decision-making process [...] to make or implement public policy or manage public programs or assets' (Ansell & Gash, 2008). The concept is primarily building on social capital (i.e., on trust, common understanding, legitimacy, and the motivation for dialogue and commitment) (Ansell & Gash, 2008; Emerson et al., 2012).

5.2.2 Relationships in flood risk governance

By date, the growing responsibilities of citizens in FRG have already been reshaping the interactions between authorities and the public which can be categorised in (Mees et al., 2018): 1) hierarchical interactions (top-down), 2) incentivised (bottom-up), or 3) deliberative (balanced). In contrast to traditional top-down interactions, bottom-up

approaches have been proven to be more efficient, at least in situations where authorities are taking a guiding role (Wu, 2020). Deliberative interactions aim to achieve 'multi-directional communication' (Mees et al., 2018) which entails the challenge of finding the ''right' balance between bottom-up and top-down governance' (Blackburn, 2014). Community-based initiatives such as flood action groups have been valuable in the process of balancing top-down and bottom-up interactions while also seeking to foster horizontal support (McEwen et al., 2018; Seebauer et al., 2019). They function as a mediator between citizens and local authorities whereas their actual engagement can be of different types i.e., contractual or cooperative (Geaves & Penning-Rowsell, 2015).

Interactions between different actors rely on relations of trust which is an omnipresent value but is also fragile and can become a barrier to action. Trust builds on the perceived confidence in an institution, and an assurance in its intention, and abilities (Earle, 2010). This perceived trust includes the expectations towards institutions (UNDP, 2021). However, trust is very dynamic and can change in response to different experiences (Seebauer & Babcicky, 2018). For instance, past flooding experiences may impact local perception of the abilities of institutions and/or confidence in those abilities. If the expectations of citizens towards them are not met, trust may diminish and perceived social contracts may evolve (Seebauer & Babcicky, 2018; Whitmarsh, 2008). The trust of citizens in authorities is of high importance, especially, in times of uncertainty or lack of personal knowledge or experience which necessitates citizens to trust in FRG actors (Felletti & Paglieri, 2019). Diminishing trust can cause long-term challenges for citizen-authority relationships (Ohman, 2017). Whereas close and long-term relationships (e.g., through accountability, participation, transparency) tend to increase mutual trust (Cumiskey et al., 2019; Seebauer & Babcicky, 2018), and help resolving existing tensions (Felletti & Paglieri, 2019). In turn, trust can foster the willingness of citizens to contribute to take and realise own responsibilities (Felletti & Paglieri, 2019; UNDRR, 2022).

5.2.3 Social contracts

Social contracts manifest (in written or unwritten form) the roles and responsibilities of actors in alignment of the societies' goals e.g., for FRM. In this regard, it is increasingly recognised that social contracts are socially-politically constructed and

therefore, are subjective, place and time-specific (Siddiqi & Blackburn, 2022; Siddiqi & Canuday, 2018). In the context of disaster risk reduction and climate change adaptation, three co-existing forms were defined (Blackburn & Pelling, 2018):

- *the legal-institutional*: describes the distribution of roles and responsibilities which are allocated in formal legislation and institutional frameworks;
- *the imagined*: how different actors' respective roles and responsibilities are perceived to be distributed which can refer to an imaginary of the status quo as it stands (i.e. how I understand things work), and an imaginary of how things should be (i.e. how I wish things would work);
- *the practiced*: this contract describes how FRM is actually executed, in terms of the embodied, performed actions, roles and responsibilities that are assumed by a particular actor/stakeholder.

In reality, all three forms can be differentiated or subjectively experienced/defined; for instance, 1) different institutions may assume a different distribution of responsibilities; 2) imagined social contracts are sensitive to socio-cultural, political, economic and other factors that shape lived everyday experience and subjective worldviews; and 3) practiced social contracts also are sensitive to dynamic and differentiated social relations that mean certain groups may perform certain roles/functions in certain situations, but not in others. It is important to understand to what extent these contracts are aligned with another (or not) because distance between imagined, practiced, and legal-institutional social contacts may indicate a mismatch between expectation and delivery (in terms of flood risk security), and/or responsibilities being differently understood between actors (Doshi & Garschagen, 2023). Such gaps are likely to impact negatively on trust and legitimacy of risk governance activities. Aiming for an inclusive co-governance of FRM, policy and practices can ensure the alignment between multiple or competing social contracts, and hence, between perceived and binding responsibilities (Adger, 1999; Oulahen, 2021).

With the aim of this study to explore responsibilities as perceived by citizens and to identify potential gaps between their perception and the legal-institutionalised responsibilities, the analysis will use the lens of the imagined and legal-institutional social contracts. Comparing these social contracts could also provide insights into how the legal and institutional framework influence the way people think about flood

risk governance. Practiced social contracts are beyond the scope of the present study, although the lived, 'de facto' experience of flood risk management practices are recognised as important in the formulation and reformulation of risk social contracts.

5.3 Methodology

5.3.1 Case study: Flooding in Germany in 2021

Flooding occurred in many areas across western Europe during July 2021. In Germany, the federal states North Rhine-Westphalia and Rhineland Palatinate were primarily affected by the low-pressure system 'Bernd', which stagnated over the area and neighbouring countries. The heavy precipitation followed a long wet early summer (Kreienkamp et al., 2021). This severe precipitation led to fluvial and pluvial flooding in hilly areas and areas with saturated soils or high groundwater tables. Inundation was additionally linked to water reservoirs that are regulated by a dam (Dietze et al., 2022; Thieken et al., 2023).

The impact of the event was severe, in many places taking the lives of more than 180 people, while three times more were injured, and many more were displaced (Lehmkuhl et al., 2022; Thieken et al., 2023). Despite a long history of flooding in Germany, this event in 2021 highlighted several remaining issues regarding flood risk management and governance in Germany, including in the following areas: 1) risk mapping and the need for impact-based forecasts (Apel et al., 2022); 2) early warning and risk communication (Bosseler et al., 2021; Fekete & Sandholz, 2021; Thieken et al., 2023); 3) the need for strengthening multi-level and multi-disciplinary collaboration (Koks et al., 2022; Mohr et al., 2022); 4) the development and practice of emergency plans and trainings (Bosseler et al., 2021); and 5) the adequacy of relief and recovery support (Bosseler et al., 2021; Kuehne et al., 2021).

Risk governance in Germany. Flood risk governance in Germany has a decentralised structure, although decision-making remains largely top-down whereby the federal level provides general guidance and standards (aligned to the EU Floods Directive (2007)), the states are responsible for fluvial and coastal flood risk management, and the districts or municipalities manage pluvial flooding. The fact that the states are primarily responsible for fluvial flood risk management, a federal framework for flooding is not given and thus, leads to differences in management across different

states (Surminski et al., 2020). In the following sections, the legal and institutional frameworks in Germany will be explored in more detail, providing an overview of the legal-institutional social contracts for FRG.

Legislative framework. Past major flooding events have shaped the legislative framework of the country. The main legislation is the Federal Water Act (Wasserhaushaltsgesetz (WHG)) which came into force in 1960 and provides guidance on the risk assessment, building regulations, and management of flood protection. The EU Floods Directive (2007) was adopted and integrated into the Federal Water Act in 2009 and further translated into state level legislation. With the addition of the first and second Omnibus Flood Control Act (2005 & 2017), flooding is supposed to be managed at catchment scale. The two acts were developed and integrated into existing water, building, and nature protection legislation. They aim for preventive flood management to reduce the impact of flooding. Following the flooding event in 2021, the Federal Government's Strategy for Strengthening Resilience to Disasters (2022) was published which represents the national implementation of the Sendai Framework (2015). In the context of climate change adaptation, the federal state North Rhine-Westphalia became a pioneer in the climate adaptation law which entered into force just a few days before the flooding event. The state-level law (Klimaanpassungsgesetz Nordrhein-Westfalen (KlAnG)) addresses inter alia the need for multi-sectoral collaboration and the engagement of citizens. By date, a draft law was developed for at federal level (Bundes-Klimaanpassungsgesetzes (KAnG)) focusing on enhancing adaptation at the municipality level, for instance, through the development of climate adaptation concepts. The law is planned to come into force towards the end of 2024. The civil protection and disaster management of the Federation (Zivilschutz- und Katastrophenhilfegesetz (ZSKG)) from 1997 describes the legislation around the protection of citizens in case of conflicts or disasters (e.g., warning of citizens).

Institutional framework. The responsibilities around flood risk management are decentralised: the German Meteorological Service (Deutscher Wetter Dienst (DWD)), which belongs to the Federal Ministry for Digital and Transport, is inter alia responsible for forecasting weather and issuing warnings according to the DWD Act. The Federal

Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (BBK)) acts as a support to the states e.g., for issuing warnings (according to the ZSKG) and is hosting the national Modular Warning System (MoWaS). The 16 federal states are primarily responsible for issuing warnings to local authorities (according to the ZSKG) and also offering flood information portals including i.e., risk maps and policies. Water authorities at state and at local level are primarily responsible for flood risk reduction measures (Puzyreva et al., 2022). While wastewater managers or companies at local level are always important actors in context of the management and maintenance of water infrastructures (Bosseler et al., 2021). Local authorities themselves are the ones who are warning the public, coordinating preparedness, response, and evacuation actions (Thieken et al., 2023). Whereas fire brigades are usually the actor who coordinates the flood preparedness and response (supervised by local authorities (Puzyreva et al., 2022). Germany encompasses a large repository of volunteers in professional organisations i.e., Technisches Hilfswerk (THW) which counts as a primary actor in flood response (Lorenz et al., 2018; Puzyreva et al., 2022). The Bundeswehr supports response and rescue operations with their soldiers, reserve forces, and especially their equipment i.e., mobile bridges, or helicopters (Juling, 2022). Communities can be involved in local decisions and action such as landscape planning and volunteered response during disasters (Puzyreva et al., 2022). Spontaneous volunteers are often involved in relief operations, but their inclusion in professional response and rescue operations is often facing challenges (Lorenz et al., 2018). Affected citizens are, according to the WHG, responsible for the protection of their property (e.g., through the implementation of protections measures).

Risk financing. The federal government has previously provided funding for flood affected citizens to aid flood recovery, for instance, after the flood in 2013, 60 % of the citizens received recovery aid funds (Platt et al., 2020). This was (partly) terminated because now, citizens are responsible for their home and property by law (Snel et al., 2022). As citizens are legally obliged to protect their properties and the government is not bound to provide flood recovery funding, citizens have less options but to consider insurance and the implementation of protective measures. Natural hazard insurance of houses in Germany follows a voluntary model although discussions are on-going to

integrate a mandatory system. The number of insured houses has risen to 50% over the past two decades (Gesamtverband der Versicherer, 2023). Citizens' willingness-to-pay for flood mitigation measures remains rather low with 50 Euros (Entorf & Jensen, 2020).

5.3.2 Online survey

An online survey was conducted targeting a wider spatial area. In contrast to other studies on this flooding event (Thieken et al., 2023; Truedinger et al., 2023), this survey is developed primarily using open questions allowing citizens to express themselves, their experiences, and opinions - in other words, to give them a voice. The questions aimed at gaining an understanding of the citizens' perspectives on the flood event in the context of early warning, preparedness, and response, but also their opinion on arisen issues and possible solutions for the future as well as their idea on the division of responsibilities.

The survey was designed as an online survey in two languages (German and English) and was disseminated via social media channels such Facebook, LinkedIn, and Twitter but also through personal channels such as WhatsApp. In fact, Facebook groups a major channel during the dissemination due to a great number of responses from flood groups founded by citizens to coordinate the response and recovery. The survey was open for responses from participants (at the age of 18 years and older) between March and July 2022.

Responses. In total, the online survey reached 438 responses (German: 434; English: 4). Respondents represent all possible age groups that were invited to participate in the survey. The representativeness of the age groups compared to the German national demographic structures (Statistisches Bundesamt, 2024) indicates that the age group 25-54 is slightly overrepresented while the citizens at the age of 65 and older are slightly underrepresented. This is an expected limitation of the social media dissemination approach. The majority of the respondents (60.5 %) were living in their own house at the time of the flood and 22.4 % were living in a rental apartment. Other respondents were living in a rental house (6.6 %), in their own apartment (4.3 %), and 3.2% at their parent's or guardian's home. Geographically, 87.7 % of the citizens were

living in North Rhine-Westphalia and 11.6 % in Rhineland-Palatinate covering in total 25 districts.

Data analysis. Pre-processing of the survey data included the translation of English responses into German and the correction of postcodes where needed. As a second step, municipality, district, and state names were added based on the post codes. Closed questions were analysed using descriptive statistics while for the analysis of open questions, thematic analysis (Braun & Clarke, 2006) was applied which allows the detection and contextualisation of patterns within the responses. The analysis was performed in four steps: 1) first familiarisation with the responses; 2) initial coding of the responses using NVivo (release 1.7.1) and Microsoft Excel; 3) themes were derived from the codes which were compared and related with another; and 5) these themes were reshuffled and merged to more overarching themes linked to risk governance and discussed with existing literature in the following Section 5.4.

5.4 Results

Two main themes emerged from the thematic analysis: 1) who flood-affected communities perceive as responsible for various tasks in FRG, which are compared to legal-institutional perspectives by adopting the framework of social contracts (Section 5.4.1); and 2) the willingness and eagerness of citizens to take action and to be more involved in local FRG (Section 5.4.2).

5.4.1 Social contracts

The imagined social contracts from the perspective of citizens showed similar visions throughout the surveyed areas. The analysis identifies the responsibilities that citizens ascribe to themselves and those they project onto authorities. Even though flood risk governance varies slightly across the municipalities and districts, most participants perceived common distributions of responsibilities of flood risk management actors.

Citizen responsibilities. Many citizens see themselves as responsible for their property and to prepare it for potential hazards as well as responding to those. This perception corresponds to the legal-institutional social contract manifested in the German Federal Water Act (WHG § 5) stating that citizens are responsible for their

private household and are ‘obliged to undertake appropriate actions that are reasonable and within one’s means to reduce flood impacts and damage’ (Bubeck, Botzen, & Aerts, 2012). Moreover, this indicates that many citizens have expanded their responsibility which may be also tracible to the fact that the federal government is not obliged to provide disaster recovery funding. Nonetheless, only a few citizens stated that they have been implementing flood protection measures in advance or during the recovery phase, while a larger share of citizens mentioned that they did not implement any (before nor after the event) due to higher costs which is in line with earlier studies (Entorf & Jensen, 2020).

> *‚... ist eine Frage der Kosten.’*
> *(In English: '... is a question of costs.')*

Just before and during the flooding event, many citizens took the responsibility of protecting their homes with short-term emergency measures i.e., saving valuable things by moving them upstairs, installing pumps, or responding to the water entering their home. Despite this legal obligation, some citizens mentioned that they did ‘nichts’ (in English: ‘nothing’). This inaction was reasoned by 1) the lack of or late warning left citizens no time to prepare for the approaching event and to protect their home; 2) some people did not know about how to behave or to act which may be linked to the lack of guidance or hazard/risk knowledge, limited hazard imagination, or no prior experience of flooding; or 3) they felt powerless.
Recovery funds were offered to home and business owners, but the process was mentioned to be bureaucratic and time intense.

> *‚Bürokratieabbau. Der Antrag auf Fluthilfe brauchte 4 Monate Bearbeitungszeit. Zum Schluss waren es 120 Seiten für 49.000€.‘*
> *(In English: ‚Reducing bureaucracy. The application for flood relief took 4 months to process. In the end it was 120 pages for €49,000.’)*

Partly, even one year after the flooding, funding requests were not processed yet. The process and the long waiting time were expressed using language of frustration and partly showed notions of distrust in the system.

Additionally perceived responsibilities of citizens that were mentioned in the survey, but are not written in any law were the following:

- Observing the surrounding natural systems in order to detect changes that can turn into hazards. While the actual share of citizens who reported that they have been observing and being attentive to changes in their environment has been rather low.
- Being alert to warnings and being proactive in seeking information as well as taking warnings seriously.
- Raising awareness and learning about potential risks and risk areas. While the responses also showed that the awareness of risk areas was very low with close to 50% who stated that they were not aware of risk areas in their neighbourhood.
- Being part of the community by warning and helping others before, during, and after hazardous events as well as helping and educating each other on these topics.

  > *'[...] ich stand bis zur Brust im Wasser um Leute da raus zu holen. Das würde ich wieder tun.' (In English: 'I stood up to my chest in water to get people out of there. I would do that again.')*

  This social connectedness can be seen as inherent value of the population which saved many lives but also risked lives during the flooding event.

Authorities' responsibilities. Besides the responsibilities citizens indicated for themselves, they perceive that most responsibilities are in the hands of the authorities at municipality, state, and federal level. Despite the general view on roles and responsibilities (as outlined in Table 1), it became appeared that they are not clearly defined in many areas: it was often directly stated that it is necessary to clarify responsibilities ('Verantworlichkeit klären'). In addition, citizens used the phrase 'responsible person/institution' (German: Verantwortlicher/-en) or just 'they' which underlines the fact that it is unclear to them who the responsible person/party is.
Principally, citizens expect authorities to guide and support them through all disaster risk management phases. These perceived responsibilities of authorities are summarised in the following Table 1 and compared to legal-institutional manifested responsibilities.

Table 1: Imagined social contracts from the perspective of survey respondents, compared to legal-institutional social contracts

Risk Management Phase	Imagined responsibilities of authorities (as perceived by citizens)	Legal-institutional responsibilities
Awareness raising	• raising awareness on potential risks (e.g., in schools) • coordination and enhancement of self-preparedness motivation of the population	Law about the civil protection and disaster management of the Federation (ZSKG) § 5 (1): the municipalities are responsible for developing, promoting and directing the self-protection of the population [...] and companies against the particular dangers that threaten in the event of a defence.
Preparedness	• preparing disaster plans and practicing these	Laws at federal level (e.g. in NRW the BHKG § 3 (3)): with the participation of their fire brigade, the municipalities have to draw up and implement fire protection requirement plans and plans for the deployment of the public fire brigade; § 4 (3): the districts have to draw up plans for large-scale operations and disasters (disaster control plans); § 5 (1): the district governments draw up alarm and deployment plans for the nationwide coordinated aid in consultation with the authorities. The Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (BBK)) offers guidance on individual/household emergency plan development.
Collaboration	• strengthening collaborations between different institutions	Hierarchical support from the government to the federal states to the districts and they support the municipalities (e.g., ZSKG § 18). The German Joint Information and Situation Centre (Gemeinsames Melde- und Lagezentrum (GMLZ)) supports the information sharing between the national and state level.
Risk reduction and mitigation	• designing and deploying risk reduction and climate change adaptation measures • maintaining existing water infrastructures • introducing stricter building regulations in retention areas	Water authorities at state and at local level are primarily responsible for flood risk reduction measures. Communities can be involved in local decisions and action such as landscape planning (Puzyreva et al., 2022). Wastewater managers or companies at local level are important actors in context of the management and maintenance of water infrastructures at all times (Bosseler et al., 2021). According to the Federal Water Act (WHG) and the laws at federal level, inundation areas are protected from the construction of new buildings or extensions. (Exceptions may be discussed with the consent of the municipality.)
Early warning	• adequately warn the population on potential risks and	The Modular Warning System (MoWaS) which was introduced in 2011 and is described as a multiplier system linked to various dissemination

	hazards, especially, at local scale considering potential power outages and the elderly • clear and transparent communication • evacuation support • warning by the fire brigade	channels (online and analogue) (hosted by the BBK). The BBK is not directly responsible for the warning but is responsible for contributing to the warning to the public (§ 4 (3) ZSKG). The meteorological service (Deutscher Wetter Dienst (DWD)) forecasts weather and issues warnings. The 16 federal states primarily responsible for issuing warnings to local authorities (according to the ZSKG § 6) but also offering flood information portals including e.g., risk maps and policies. The municipalities together with the districts are the ones who are warning the public § 3 (1) BHKG. The fire brigades are mainly acting in response and support evacuation but also last-minute warning (Puzyreva et al., 2022).
Emergency response	• coordination of volunteers • having an overview of the situation and conducting assessments for better disaster management • organising rescue operations, shelters with adequate care/supplies, and volunteers	According to the THWG law, the governmental non-profit organisation Technical Relief (Technisches Hilfswerk (THW)) is one of the primary actors in flood response. Fire brigades are often supervised by municipalities who coordinate flood preparedness and response. Communities can be involved in volunteered response during disasters (Puzyreva et al., 2022).
Recovery	• provide fast and unbureaucratic financial support in the aftermath of the event and financial benefits for moving away to safer places • taking care of calls for donations • offering psychological support for affected people, occupational safety, and showing empathy to affected citizens	Officially, the government is not legally bound to provide flood recovery funding, therefore, citizens need to consider insurance. Discussions on whether insurance should be made compulsory are on-going since several years (Snel et al., 2022). Calls for donations are organised by various institutions e.g., district or municipality level, by aid agencies such as the red cross or Aktion Deutschland hilft but also by the diaconia. Psychological support is often offered by public and private practices and may be paid e.g., through health individual insurance.

Comparing the perceived responsibilities of citizens against the legal-institutional social contracts in Table 1, it was found that multiple perceived responsibilities are reflecting what is written in laws, while other areas of responsibility are not clearly defined in either. Those that are not clearly defined include:

- Citizens expect that risk awareness campaigns/communication falls to local authorities, and that authorities should motivate citizens to prepare for

potential hazards. Respondents did not acknowledge that effective risk communication requires citizens to accept or be open-minded to these awareness raising actions.

- The preparation of disaster plans and practicing these is partly fulfilled by local and national authorities but primarily linked to fire hazards; while the practice of plans is not actively including the public (e.g., the national alarm day positioned citizens as the receptors of siren and cell broadcasts alarms but does not actively involve them in practices, for instance, in evacuation practice).
- By law, vertical collaboration and support in the federal system is prescribed but does not specifically focus on horizontal or multi-sector collaboration and communication. This is significant considering the diversity of actors involved in or who are impacted by risk and emergency management.
- The responsibilities around the inclusion and coordination of first-response volunteers recruited at short notice or assuming roles spontaneously are not clearly defined, which can lead to chaos during emergencies.
- Recovery funding is expected to be paid to affected citizens, however some citizens did not see it as their own responsibilities to insure their property.
- Citizens raised the point that authorities should take responsibility for providing psychological support or occupational safety for affected citizens. This role is not clearly set.

Looking at the distribution of responsibilities in the context of shared responsibilities, it appears that responsibilities are perceived to be spread between various actors including citizens. However, the allocation of responsibilities indicates a strict segregation between the responsibilities of citizens and the authorities. In other words, responsibilities are perceived to lie either within citizens or authorities, and only rarely as a *joint responsibility*.

Citizen-authority relationships. The survey responses did not provide a deep insight into interactions between citizens and authorities. In some cases, hierarchical (top-down) interactions were implied. Examples for this were when citizens wrote about expecting to receive help and information. However, hints towards bottom-up or deliberative interactions (Mees et al., 2018) could not be distilled from the responses.

Throughout the survey responses, respondents highlighted that their expectations of local authorities and the federal government were not met in many ways:

> *‚Der Katastrophenschutz hat versagt.‘*
> *(In English: ‚The civil protection/disaster management has failed.‘)*

Such responses, suggesting the entire civil protection mechanism did not uphold their proper duties, lacking specificity about which abilities were actually expected from which arms or departments (often because it is not known who is specifically responsible for each different action). In contrast, the following response is more specific by stating that the person expected the responsible people should have taken the weather forecast serious:

> *‚Die Verantwortlichen Personen haben die Vorhersage nicht ernst genommen.‘*
> *(In English: , Those responsible did not take the forecast seriously. ‘)*

In particular, inadequate or poor management of the authorities and government (as expected by citizens) has been one major reason for declining trust and expectations. This primarily refers to issues around warning and information flows or lacking recovery support. Diminishing trust was demonstrated in statements showing lacking confidence in the intentions and capabilities of the authorities:

> *‚Verlogenheit, Lügen, Schummeln.‘*
> *(In English: ‚Mendacity, lying, cheating.‘)*

> *‘Von den Regierungen erwarte ich nach Covid-19 und dem Hochwasser nichts mehr.’*
> *(In English: ‘I don't expect anything more from governments after Covid-19 and the floods.’)*

Some expressed such low trust in authority, that it is better to not place trust in others (e.g., authorities), and rather take responsibility themselves:

> *‚Kein Vertrauen in die Verantwortlichen.‘*
> *(In English: ‚No trust in those responsible.')*

5.4.2 Willingness to engage

Several citizens reported involving themselves in emergency management and recovery actions, either through their volunteering organisation, calls for help in social media, but also through spontaneous volunteering (e.g. to support local fire brigades). In some areas, local Facebook groups were founded to help allocate help during and after the event. These groups were very active, for instance, in donating furniture, providing hands-on support to affected persons, and sharing personal experiences for psycho-social support. The survey responses indicate that a large amount of the recovery effort was primarily performed through local communities and people from outside willing to help. However, the coordination of spontaneous (eventually untrained) volunteers was not organised (efficiently) in some areas:

> *‚…unkontrollierte Masse freiwilliger Helfer verstopfte die wenigen Straßen die frei waren; freiwillige Helfer bildeten eigene Substruktur, die eigenmächtig Entscheidungen traf, weil Behörden nicht präsent waren (z. B. eigenmächtige Sperrung von Straßen, eigenmächtige Einbahnstraßenregelung).‘*
> *(In English: '…uncontrolled masses of volunteers clogged the few streets that were free; volunteers formed their own substructure that made decisions on their own initiative because authorities were not present (e.g., unauthorized closure of streets, arbitrary one-way street regulation).’*

Despite their loose organisation and the chaos of the situation, spontaneous volunteers were highly valued, and respondents highlighted a need for better volunteer coordination – for example, by establishing mixed teams of trained (i.e., members of the voluntary fire department) and spontaneous volunteers (citizens).

Overall, citizens demonstrated a high level of willingness to engage in local decision-making and actions around disasters risk management and climate change (see 7). About 70 of 438 participants prefer not to be engaged in local activities. Some citizens felt that they already volunteer in too many places (thus, more engagement would be

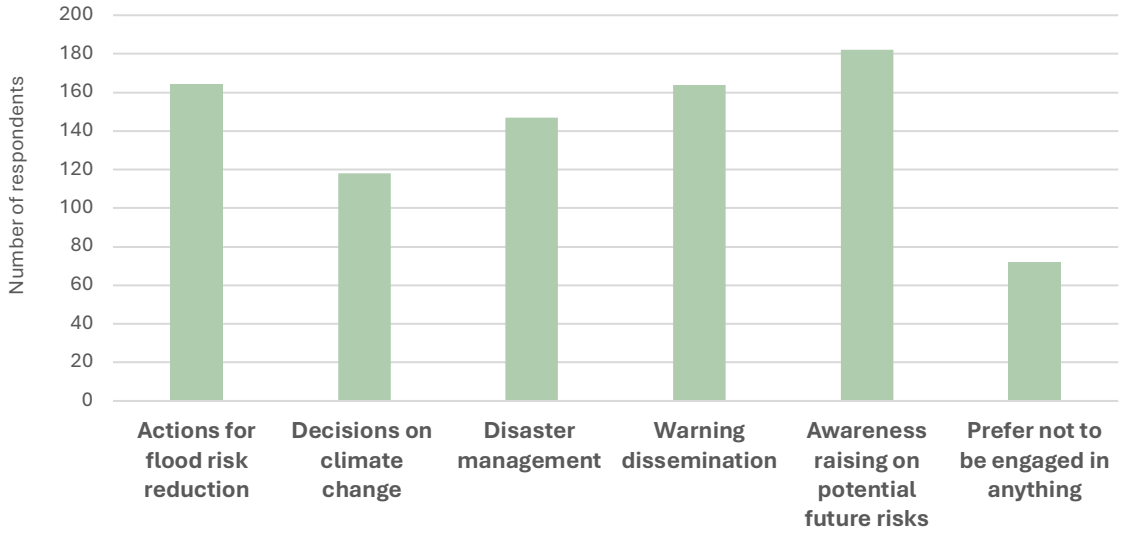

Figure 7: Number of people willing to be more engaged in local decision-making and actions

too overwhelming), while others do not feel healthy enough or prefer to volunteer only spontaneously.

One theme that stood out was that individual citizens felt unable to initiate changes in FRM, and that the changes in policy and practice can only be initiated by local authorities or politicians. This felt lack of agency or influence was expressed, for instance, in the following quote:

> *‚Bei dem letzten Hochwasser, sind die Bürger die Letzten, die etwas hätten tun können, sie sind die falschen Adressaten etwas zu verändern.‘*
> *(In English: 'During the last flood, the citizens were the last ones who could have done something, they are the wrong recipients to change something.')*

The reasons for this could be limited or restricted access to resources (J. C. Morris et al., 2019), and indeed, it can be difficult for a citizen alone to foster a change in a community. One mechanism for leveraging change can be via local groups, such as flood action groups. One participant reported that they founded an initiative with citizens from their village and surrounding locations in the district of Aachen. It was mentioned that the Hochwasserschutzinitiative (flood protection initiative) has already achieved multi-directional interactions with relevant stakeholders and authorities, opening possibilities they felt for initiating a change in FRM practice:

> *‚Wir haben mit vier betroffenen Orten, Hahn, Friesenrath, Sief und Kornelimünster eine Hochwasserschutzinitiative gegründet und eine bisher gute Kooperation mit der Stadt Aachen und den entsprechenden Fachbehörden.'*
> *(In English: 'We have founded a flood protection initiative with four affected towns, Hahn, Friesenrath, Sief and Kornelimünster, and have so far had good cooperation with the city of Aachen and the relevant specialist authorities.')*

5.5 Discussion and implications for policy and practice

This study explored the allocation and perception of responsibilities for risk governance before, during, and after the 2021 flooding event in Germany. Key lines of exploration include the (perceived) distribution of responsibilities of different actors, reflections on trust, local willingness to engage in local actions and decision-making, and links between these.

Flood risk governance in Germany is decentralised in the sense that roles and responsibilities of flood risk management are distributed to multiple actors and across scales (Dordi et al., 2022; Matczak & Hegger, 2020). In spite of this, a hierarchical structure (Mees et al., 2016) persists due to the fact that citizens are positioned and are perceiving themselves as the final receivers of risk management, including in the areas of risk communication, information dissemination, and help. This deep-rooted deference on formal institutions was reflected in the citizens' perspectives on the flood governance as most of them expect to be totally guided through the different flooding phases - from awareness raising to recovery.

Comparing the imagined and legal-institutional social contracts, there are broad areas of alignment whilst there are also several aspects where roles and responsibilities need to be clarified. Overall, citizens had many expectations towards local authorities, volunteer organisations, and the state and federal government, whilst they ascribed less responsibilities to themselves. This indicates a great dependency of citizens on 'others' in cases of emergency. The survey responses highlighted the fact that citizens are often projecting responsibilities onto others while not being certain who the 'other' entity actually is. These unclarified responsibilities can be a barrier for flood risk governance (Bisaro et al., 2020; Blackburn, 2014; Dieperink et al., 2018; Hegger et al., 2014; Snel et al., 2022).

As well as allocating most responsibilities to authorities, citizens also have high expectations regarding their management. This insight is comparable to the outcomes of study on different notions of responsibility in Germany (Snel et al., 2022). However, the responses of this present survey showed that these expectations were not met in many ways, and this has affected citizens' trust in authorities. This extends earlier research on trust which finds that previous experiences can influence trust positively or negatively (Seebauer & Babcicky, 2018). Trust is an important value for cooperation (Earle, 2010); thus, trust needs to be rebuilt to enable interaction and collaboration between citizens and authorities.

The majority of citizens were aware of their own responsibility (set by law) of protecting their property and house from flooding, which was defined as a common first step towards shared responsibilities (Henstra et al., 2019). Nonetheless, the survey underlined that this responsibility is largely dependent on information and guidance by authorities. Overall, citizens understand this responsibility from a more reactive/defence perspective than implementing flood protection measures in advance. This was partly related to the costs of flood protection measures which has long been viewed as a key barrier to preparedness in Germany (Bubeck, Botzen, & Aerts, 2012; Entorf & Jensen, 2020).

It can be concluded that actual multi-directional interaction (Mees et al., 2018) and close long-term relationships (UNDRR, 2022) between citizens and authorities would benefit FRG in multiple ways (Chambers, 1983; Fekete & Sandholz, 2021; Puzyreva et al., 2022; Renn, 2015; Snel et al., 2022) and increase trust (Cumiskey et al., 2019). Citizen-authority interactions and collaboration are essential to align perceived social contracts, clarify roles and responsibilities, engage citizens, enhance multi-directional communication and collective decision-making, and lastly, to build trust (Ansell & Gash, 2008; Emerson et al., 2012).

The following subsections (5.5.1 and 5.5.2) will discuss the two major needs identified above by further proposing policy and practice recommendations.

5.5.1 Aligning perceived and legal-institutional social contracts

The comparison of social contracts has shown that there are several differences between the imagined and the legal-institutional ones, but also that some responsibilities are not clearly defined or allocated. Transparent and inclusive

discussions on the distribution of responsibilities are important to move ahead in flood risk governance (Snel et al., 2022). Therefore, we conclude that the co-production or co-development of a shared risk social contract with all actors, including citizens, is of high importance to ensure that different visions of fair or 'correct' FRG are aligned with one another, and that the distribution of rights and responsibilities is socially acceptable to all (Adger, 1999; Doshi & Garschagen, 2023; Mees et al., 2018; Oulahen, 2021).

The current perceived distribution of responsibilities by survey respondents further indicated that responsibilities are shared between different actors but not jointly. In this regard, it is important to identify responsibilities that can foster, firstly, the collaboration between citizens and other FRG actors and, secondly, the sharing of responsibilities in the sense that multiple actors have joint responsibility (Matczak & Hegger, 2021; Mees et al., 2018).

Implications for policy. The survey responses highlighted that roles and responsibilities need to be freshly explored, defined, and manifested at local level involving the general public. This should include 1) clearly and transparently communicating existing roles and responsibilities; 2) identifying more gaps – roles and responsibilities that are perceived by citizens but are not clearly manifested (or vice versa); 3) elaborating joint responsibilities between different actors including the general public. These processes need to go beyond public involvement by approaching co-produced flood risk governance (Evers, 2012; Mees et al., 2018). It is of importance to not only allocate certain responsibilities to actors but to agree (as far as possible) on the proposed arrangements to increase the willingness to take the responsibility (Snel et al., 2022).

It is recommended to establish local flood (or adaption) committees - comprising citizens, local citizen groups (e.g., flood action groups), and representatives from local FRG actors - which will foster collaboration whether horizontal, vertical, multi-sector, multi-disciplinary, or with citizens (McEwen et al., 2018; Mees et al., 2018; Snel et al., 2022). Community-based initiatives such as flood action groups can be valuable in the process of balancing relatively top-down and bottom-up interactions because they can function as a mediator between citizens and local authorities (Geaves & Penning-Rowsell, 2015; McEwen et al., 2018).

Implications for practice. In practical terms, there is a need to start or enhance civil dialogues to build consensus and applying participatory methods and tools to involve citizens to a greater and more impactful extent (Chambers, 1983; Evers, 2012). These dialogues may be more effective if initiated by the municipalities (or districts) to ensure the actual adoption of the dialogue outcomes in the future (Ansell & Gash, 2008; Emerson et al., 2012). In the context of climate adaptation, it will be beneficial to perform this exercise with a multi-hazard and systemic risk lens (UNDRR, 2022). Collaboration but also trust can be increased by creating joint responsibilities between citizens (groups) and local authorities (Cumiskey et al., 2019; Earle, 2010; Seebauer & Babcicky, 2018). In this regard, a few 'joint responsibilities' were identified within the survey that can function as starting points for collaboration between citizens and local authorities: 1) identification of local thresholds, observation of the environment, and communication between another on hazardous developments; 2) raising awareness and learning about potential risks within the community; 3) supporting the dissemination of official warnings and enhancing action taking within the community by building on their social interconnectedness.

5.5.2 Enhancing multi-directional interaction

In the context of co-developing or refining social contracts, one important aspect is multi-directional interaction (bottom-up and top-down) but also in a broader picture, the strengthening of this type of interaction between citizens and other actors was identified above as one major need (Adger, 1999; Mees et al., 2018). Citizen's active involvement in different forms entails many proven advantages, but of course, it also requires expertise, time, and other resources (Dieperink et al., 2018). The survey indicated that citizens remain greatly dependent on risk and emergency management systems which was also found in another study (Fekete & Sandholz, 2021). Multi-directional interaction would empower citizens, rebuild trust, raise awareness, and create ownership which can increase the willingness to take responsibilities (Felletti & Paglieri, 2019; Mees et al., 2018; UNDRR, 2022). Hence, the survey results highlighted the need for bridging the interface between authorities and citizens while participants showed a strong willingness to be engaged in local activities and decision-making.

Implications for policy. This flooding event reiterates the continued need for enhancing bottom-up approaches in flood risk management in Germany to gradually decrease the dependency of citizens on the infeasible idea of a perfect system and to build resilience. This requires greater involvement of citizen groups which may emerge through self-organisation (due to flooding experience) or are founded in alignment with existing laws (Matczak & Hegger, 2020; Seebauer et al., 2019). On the other hand, it requires that municipalities are acknowledging these groups and are actively involving them in local decision-making and actions (Emerson et al., 2012). Legislation, strategies, and concepts need to emphasise the multi-directional interaction since citizens' participation, if mentioned, does not take a central role, yet (Mees et al., 2018).

Implications for practice. The need to bridge the interface between local authorities and citizens may be in different degrees across municipalities. In practical terms, multi-directional interaction refers to the idea that needs, decision-making, and actions can be developed in collaboration (Evers, 2012; Mees et al., 2018). In fact, in several countries and also in a few areas in Germany, flood action groups were founded (commonly after flooding events), and these can function as a bridge between the citizens and the local authorities (Geaves & Penning-Rowsell, 2015). For instance, initiatives in the UK started dialogues and collaboration with local authorities (McEwen et al., 2018). These groups can be a steppingstone for creating joint responsibilities such as engaging in awareness raising, implementing flood risk reduction measures, or in preparedness and response activities. However, for bottom-up initiatives, it can be difficult to be 'heard' by local authorities and be involved in decision-making (Emerson et al., 2012); thus, in the sense of collaborative governance (Ansell & Gash, 2008), a first step is to enhance collaboration and rebuild trust which could be initiated from the side of local authorities.

5.6 Conclusion

This study's overarching aim was to examine how citizens perceived the adequacy of flood risk governance before, during, and after the devastating flooding event in Germany in July 2021. It has focused, specifically, on citizens' subjective visions of how roles and responsibilities for FRG are or should be allocated. In this regard, the

study compared the alignment (or not) of the perceptions with formal legal-institutional risk governance structures. For this purpose, a semi-structured survey was disseminated via social media in flood affected areas. For the analysis of survey responses, this study applied the lens of social contracts. The analysis showed that the distribution of responsibilities in flood risk governance are partly differently imagined by citizens as they are legally-institutionally manifested. In addition, responsibilities show signs of segregation – meaning that there are no joint responsibilities between citizens and other actors. Overall, the difference in imagined and legal-institutional social contracts showed a remaining high dependency of citizens on other flood risk governance actors and a functioning system. Moreover, citizens expectations towards flood governance actors and the fact that they were not completely met before, during, and after the event, has cause the decrease of citizens' trust in authorities. Reflecting on the findings above, two major needs around flood risk governance were distilled: co-developing social contracts and enhancing multi-directional interaction.

This study indicates that research on governance structures and citizen involvement remains several steps ahead of policy and practice implementation. Yet, in support of the policy and practice implications provides, more research is needed on social contracts in practice, for instance, how can social contracts efficiently and satisfyingly be co-developed between citizens and local authorities. In addition, more research is needed on effective multi-directional interaction between local groups and authorities at different levels and how trust can be rebuilt in the German context and existing governance structure.

The adoption of the social contracts lens was important to understand differences between perceptions and the legal-institutional frame. To gain a fuller picture, it will be important to compare these results with the practiced social contracts as they could eventually provide more insights into why citizens perceive roles and responsibilities the way they do. Furthermore, using a semi-structured survey was useful for gathering a broad range of different responsibilities. However, considering that citizens have varying perceptions on responsibilities, the survey design did not allow to distil whether all imagined social contracts of the citizens are widely in alignment. Finally, the survey dissemination strategy of using social media channels

might have influence the participants group in terms of age, living status, and eventually the level of flood awareness and self-responsibility.

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6 Empirical Chapter III: Turning regret into future disaster preparedness with no-regrets

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Abstract. Global efforts are focusing on long-term preparedness for disasters highlighting the need for taking well-informed decisions in advance to avoid panic behaviour when a disaster strikes. Taking well-informed decisions includes the evaluation of the potential outcomes of a decision or action to avoid regretting them afterwards. Yet, little is known about what we regret about our actions and inactions in the context of disasters. Using the responses of a survey disseminated in flood affected areas in German in 2021, this study dives into the regrets of citizens and the reasons for their regrets. The results showed that participants only regretted preparedness actions when they threatened their life, but foremost, participants regretted their inaction. Overall, the results indicate the need for promoting long-term preparedness which can be supported with no-regrets actions which in addition need to be easy-to-implement. Furthermore, the need for integrating actions supporting psychological preparedness was identified. To increase citizens preparedness motivation, their self-responsibility needs to be enhanced which could be achieved through fostering collective action.

Key words: Adaptive Capacity, Disaster Risk Reduction, Inaction, Imagination

6.1 Introduction

> *'I was woken up by the rising water as I swam across the room on my couch.' (Original: 'Ich wurde von dem steigenden Wasser geweckt, als ich mit meiner Schlafcouch durchs Zimmer schwamm.')*

After a flood, we would probably reflect on the moment when we woke up on the couch because it was floating through the room. In this moment, we would start thinking what if I had received a warning and prepared for the flood. The reflections on the past and thinking about the 'what if' can make us regret decisions and actions that had negative outcomes, or actions we failed to take (G. Feldman & Chen, 2019; J. Feldman et al., 1999; Gilovich & Medvec, 1994; Zeelenberg et al., 2002). Regret is an emotion of blaming ourselves, but regret and the experience itself, also supports us in adapting for future flooding (Hung, 2020; Kuang & Liao, 2020; Zeelenberg & Pieters, 2007).

The floods in Germany of July 2021 have left many regrets but also starting points for enhancing future disaster preparedness. Although, the event was forecasted well in advance at both European and national level (Thieken et al., 2023), the floods took hundreds of citizens by surprise because they did not receive any warning or did not take warnings seriously (Fekete & Sandholz, 2021). Those citizens who did not expect flooding, did not have had time to prepare and, therefore, were overwhelmed by the water entering their homes (Lemnitzer et al., 2021; Thieken et al., 2023). The lack of preparedness together with people taking risky actions such as driving through flood water or going downstairs into flooded basements caused a high number of lost lives (Thieken et al., 2022).

The floods further reminded us that many citizens have a rather reactive or flood defensive mindset, rather than a proactive one (Ommer, Blackburn, et al., 2024; Surminski & Thieken, 2017). Rare events like this disaster are deeply uncertain and therefore, need to be adapted to in advance rather than taking action only after a warning (which sometimes may not arrive) (Marchau et al., 2019). A proactive mindset can enhance our ability to act fast when we receive a warning which otherwise perhaps results in irrational, reflexive, or panic decision taking (Geaves et al., 2023; Xenidis & Kaltsidi, 2022). Hence, for taking good decisions on preparedness actions, we need time to evaluate the potential impact of our actions to ensure that we will not regret

them in the future (Robinson & Botzen, 2018; Sunderrajan & Albarracín, 2021; UNDRR, 2022).

This raises the research question of which actions do we actually regret and why do we regret them. Commonly communicated preparedness actions include preparing the home for intruding water by moving valuable things upstairs, installing pumps in a basement, or preparing an emergency kit (Kreibich et al., 2011; Martins et al., 2019). These actions can be performed in a relatively short time, for instance, after receiving a warning. Although, these actions taken are very valuable for protecting our home and properties, they were recently claimed as 'weak preparations' where we are 'blindly following' instructions (Katsikopoulos, 2021). In fact, (proactive) disaster preparedness shall target the strengthening of knowledge and capabilities 'to effectively anticipate, respond to and recover from the impacts' (UNDRR, 2017) which may not be always achieved with so-called weak preparedness actions. Hence, stronger and long-term preparedness actions rather include developing a (household) emergency plan and practising it (Katsikopoulos, 2021).

Considering that the uncertainty about whether we will be affected by a hazard or not (especially, if we have no prior hazard experience) is one major barrier to long-term preparedness, an interdisciplinary strategy for decision-making under uncertainty could be applied: the no-regrets approach (Marchau et al., 2019). First integrated into climate policies in the 1990s, the no-regrets approach fosters taking actions which are robust in different future scenarios (i.e., no, low, or high impact hazards). According to Heltberg et al., (2009), actions shall firstly, not be regretted in any future scenario, and secondly, not be costly, and entail benefits. These values have motivational factors to take the actions since our decisions are driven by the aim to avoid regret but also by economics and benefits which are representing a reward (Sunderrajan & Albarracín, 2021).

The no-regrets decision-making strategy was later adopted in disaster risk reduction research (Debele et al., 2023; Heltberg et al., 2009; Plume, 1995), but has not been applied in context with individual disaster preparedness. Gaining a better understanding of the regrets linked to flood preparedness can help shape advice on preparedness behaviour for citizens. For this purpose, this study explores the flooding event in Germany in 2021 from a regret perspective. Using an online survey disseminated in flood affected areas, this study dives into citizens' preparedness

actions before the event and for the future. The main objective is to gain insights into what participants regretted, or not, and why. Acknowledging that regret is a cognitive process and therefore, highly subjective, this study aims to derive a broad overview on potential regrets of citizens. Secondly, the outcomes of the survey will then be used to form recommendations for long-term disaster preparedness and the suitability of the no-regrets approach as a framework for individual disaster preparedness.

To learn more about the flooding event, Section 6.1.1 provides a summary about the floods and impacts. Section 6.2 presents the survey design and data analysis. The results providing insights into the regrets and no regrets are discussed in Section 6.3 and a conclusion towards long-term disaster preparedness is provided in Section 6.4.

6.1.1 The floods in Germany in 2021

The low-pressure system 'Storm Bernd' brought heavy precipitation in Western Europe between 12th and 15th July 2021 which cascaded into flooding and caused devastating impacts (Kreienkamp et al., 2021; Lemnitzer et al., 2021).

Germany (and its neighbouring countries) experienced severe rainfall after a three-week-period of wet days (Dietze et al., 2022). While heavy rainfall hit many parts of the country, the federal states Rhineland-Palatinate and North Rhine-Westphalia experienced particularly high amounts of precipitation causing local flooding. The two states are located in the western region of Germany bordering to the Netherlands, Luxembourg, Belgium, and France. In these states, many small and medium sized rivers exceeded their banks during the flooding event (Lehmkuhl et al., 2022).

Heavy precipitation of up to 180 mm within 72 hours led to various types of flooding (Dietze et al., 2022; Junghänel et al., 2021; Lehmkuhl et al., 2022). The initial high saturation level of soils led quickly to surface runoff and pluvial flooding (Dietze et al., 2022). While the runoff on hillslopes transformed into small streams forming gullies (Lemnitzer et al., 2021). Flash floods occurred in the middle hills' catchments where steep slopes are a common landscape feature (Thieken et al., 2023). Additionally, water reservoirs filled up quickly and proved danger to their dams and the downstream population (Lehmkuhl et al., 2022). Lastly, urban fluvial flooding occurred in cities along rivers and streams (Thieken et al., 2023).

In Germany, about 162 km^2 were inundated, primarily affecting the agricultural sector with 88 km^2 of flooded agricultural land (He et al., 2022). Overall, the floods led to

devastating damages of EUR 32 billion (Mohr et al., 2022). The damage to roads, bridges and other critical infrastructure further complicated evacuation and emergency response (Fekete & Sandholz, 2021; Koks et al., 2022). Most importantly, more than 180 people lost their lives and hundreds of people were injured or displaced (Dietze et al., 2022; Thieken et al., 2023). According to an evaluation in the federal state North Rhine-Westphalia (Thieken et al., 2022), most people lost their lives in their cars, on the street, in a basement, or on the ground floor. Most of these people drowned in the flood waters, a few lost their life due to heart failure, and two because of burn injuries from oil-fired heating.

The event was referred to as 400-year event but highlighting the fact that these kinds of events can occur more often (Kreienkamp et al., 2021). The results further suggested an influence of climate change on the intensity of the rainfall event and future ones. According to another study, land cover changes, for instance in America, could further intensify these rainfalls in the future (Insua-Costa et al., 2022).

6.2 Methods

6.2.1 Online survey

To gain a better understanding on the perspective of affected citizens on this event, an online survey was designed to gather a spatially wide collection of responses. To give these citizens a voice, the survey (Appendix 1-2) encompassed primarily open questions regarding the flood source, risk estimation, preparedness, response, early warning, issues that were perceived and suggested solutions for these, and basic demographic questions (age, living situation, and postcode). The survey was designed in two languages (German and English). After approval by the SAGES Ethics Committee of the University of Reading (February 2022), the survey was open from March to July 2022 and invited flood affected citizens (18 years and older) from the two states Rhineland Palatinate and North Rhine-Westphalia to share their experiences. It was disseminated using Microsoft Forms via social media channels such as Facebook, Twitter, LinkedIn, and WhatsApp. The nature of the design of the study and dissemination strategy could lead to biases (i.e., Ong et al. (2023) in age groups, risk awareness, or the personality of participants as it may have promoted the participation of generally more active and engaging people.

6.2.2 Data analysis

The responses were stored in Microsoft Excel and pre-processed which included the translation of responses in English, the correction of postcodes, and the adding of municipality and district names (based on the postcodes).

Descriptive statistics were used to analyse basic questions regarding age structure and living situation, location, and flood experience. In total, 438 responses were collected. The majority of participants (87,7%) were living in North Rhine-Westphalia at the time of the flooding and 12,3% in Rhineland Palatinate. 65% of the participants were aged between 25 and 54 years but also covered the age groups 18-24 years (6%), 55-64 years (19%), and 65 years and older (9%). The age structure of the survey participants is comparable to the German national age structure of 2022 (Statistisches Bundesamt, 2024), but shows a slight overrepresentation of the age group 25 to 54 years. Almost two thirds of the participants were owning a house in July 2021, and about one-fifth were living in a rental apartment. Other participants were living in a rented house (7%), owning a flat (4%), or living with their parents or guardians (3%).

Open questions were analysed qualitatively utilising thematic analysis (Braun & Clarke, 2006). This allowed a deeper insight into the survey results by identifying overarching themes. Applying the thematic analysis, all questions were analysed to distil themes that appear across these questions. The workflow included the familiarisation with the responses followed by an initial coding in Nvivo (release 1.7.1) which highlighted the themes of inaction and regret. Using Microsoft Excel, these themes were explored in more depth by manually coding the responses into i.e., reasons for inaction. The results of the thematic analysis are presented and discussed in Section 6.3 and concluded in Section 6.4.

6.3 Results

Overall, participants implied different regrets about their preparedness behaviour, especially, about the actions they did not take – their inaction. Regret was expressed in what they would do differently if another flood approaches in the future. This showed that the participants have been evaluating their actions and inactions and probably thought about what they could have done (differently). This reflection and the question of ‘what if’ is a typical process that can lead to regret (J. Feldman et al., 1999; Zeelenberg et al., 2002). What participants regretted and why is discussed in the

following Section 6.3.1. In contrast, Section 6.3.2 discusses what participants did not regret and indications for why.

6.3.1 What do we regret?

Overall, participants mentioned that they undertook a variety of short-term emergency measures (Kreibich et al., 2011; Martins et al., 2019) such as preparing the house and basement for potential water intrusion, moving valuable furniture, documents, photos, and more upstairs, preparing emergency escape bag packs, storing food, and filling water canisters. Interestingly, none of the participants mentioned that they regretted having taken any of these actions. Only if the action caused a threat to the life of the participant, then regret was expressed.

> *'I cleaned out the basement.*
> *Which, in retrospect, was very dangerous. I wouldn't do that anymore.'*
> *(Original: 'Ich habe den Keller ausgeräumt.*
> *Was im Nachhinein sehr gefährlich war. Das würde ich nicht mehr machen.')*

This can be explained by the regret theory that when an action had or might have had a negative outcome, we start thinking about the 'what if' – imagining what we could have done differently to achieve a more positive outcome (Zeelenberg et al., 2002). In the above quote, the participant recognised afterwards that going into a flooded basement can be very dangerous, indeed drowning in the basement was one of the major threats of this flooding event (Thieken et al., 2022). Causes of death were also linked to driving or walking in flood water which was regretted by another participant.

> *'Stay at home and stop trying to drive the car.'*
> *(Original: 'Zuhause bleiben und nicht mehr versuchen mit dem Auto zu fahren.')*

Similarly, negative outcomes were associated with the trust in the early warning. Flooding was largely unexpected by the survey participants primarily because of untimely, late, or no warning. Roughly half of the participants did not receive any warning considerably in advance of the event (24h or more). Asking the participants when they received the first warning, about 20% did not receive any warning before the water arrived, 26% noted that they received warning only a few hours before and about

14% were 'warned' by the arriving or entering water itself. Not receiving warning in time left several participants in the situation that they had to evacuate immediately. In this context, participants highlighted that they regret to trust in the dissemination of early warning and the support by the local authorities which they see as the cause for this stressful and dangerous situation they found themselves in.

> *'No warning' – 'Escape' – 'Trust no one' – 'Do everything (differently)'*
> *(Original: 'Keine warnung' – 'Flucht' – 'Keinem vertrauen' – 'Alles (anders machen)')*

> *'I no longer rely on warnings! In case any come!!!*
> *Keep an eye on the surroundings/nature myself.'*
> *(Original: 'Ich verlasse mich nicht mehr auf Warnung[en]! Falls welche kommen!!!*
> *Selber die Umgebung/Naturi m Auge behalten.')*

Their intent for the future was to not trust nor depend on local authorities and warnings. Trust is an important pillar for the relations between citizens and authorities which is especially needed in emergency situations (Earle, 2010). However, trust is very dynamic and fragile (Seebauer & Babcicky, 2018); thus, it is often observed that after a devastating event, the trust in authorities diminishes if expectations are not reached (Seebauer & Babcicky, 2018; Whitmarsh, 2008). This case shows how the regret has initiated that participants are willing to take more responsibilities which is a typical effect of regret (Zeelenberg et al., 2002). At the same time, these participants now aim to be more proactive by taking measures in advance and being more attentive to the nature and environment to detect changes to avoid surprises in the future.

> *'Now, one is aware of what 200L/sqm means. With similar amounts, I would have packed my suitcase long ago and would move to higher elevations for safety.'*
> *(Original: 'Jetzt ist man sich bewusst was 200L/qm bedeutet. Bei ähnlichen Mengen hätte ich schon längst den Koffer gepackt und würde mich in Höhere Lagen in Sicherheit bringen.')*

In this context, one participant implied regrets about the person's own knowledge and threat appraisal. In this case, the person perhaps did not have enough knowledge or

information about what 200ml of rain would mean and hence, had to take decisions under greater uncertainty (Marchau et al., 2019).

> *'Public warnings are not reliable.' – 'No trust in those in charge' – 'Escape' – 'Take all measures in advance yourself to avoid being caught off guard.'*
> *(Original: 'Auf die öffentlichen Warnungen ist kein Verlass.' – 'Kein Vertrauen in die Verantwortlichen.' – 'Flucht' – 'Selbst im Vorfeld alle Maßnahmen treffen um nicht überraschend zu werden.')*

In disaster situations, it is important to take well-informed decisions which involves considering the potential outcomes of a decision (Sunderrajan & Albarracín, 2021; UNDRR, 2022). These surprise moments have left participants no or minimal time; thus, decisions were made in panic or reflexive leading to irrational action taking (Geaves et al., 2023; Xenidis & Kaltsidi, 2022).

> *'I tried to save things and forgot important things. One acts irrationally.'*
> *(Original: 'Ich habe versucht Dinge zu retten und habe wichtige Dinge vergessen. Man handelt irrational.')*

Overall, many regrets were related to time as participants would have like to prepare earlier ('*früher*'), in time ('*rechtzeitig*'), or immediately ('*sofort' 'direkt handeln' 'zeitig'*).

> *'In the short time, less than an hour before the event, there was nothing more one could do.'*
> *(Original: 'In der kurzen Zeit, keine Stunde vor dem Ereigniss, konnte man nichts mehr machen.')*

The majority of regrets expressed by participants were related to inaction. Missing the chance to take actions because of different reasons is another common cause for regret (Gilovich & Medvec, 1994). 29.6% of the participants wrote that they did nothing ('nichts', 'nix') as preparedness. This preparedness inaction was primarily linked to the lack of time to take action because of the unexpectedness of the event. More reasons for not preparing were the fact that people were e.g., sleeping (since the flooding started during the night in some areas); they were not at home; they did not understand

the warning properly; they could simply not imagine an event like this; they did not know what to do; or they could not act because they were not the legal owners.
Inaction regrets were found in regard to flood mitigation and preparedness measures, evacuation, seeking information, and helping others. Considering the debate in research about whether actions or inactions are more regretful (G. Feldman & Chen, 2019), it can be concluded that in this real-life experience, inactions were regretted more as participants perhaps wanted to take actions but could not because there was not enough time.
Inaction was further explained by the fact that participants did not take the received warnings seriously which they regretted afterwards.

> *'Unfortunately, I did not pay enough attention to the warning, so [I prepared] nothing.' (Original: 'Ich habe der Warnung leider nicht genug Beachtung geschenkt, also nichts [vorbereitet].')*

One reason for not taking the warning seriously was that there have been too many warnings, especially, also considering the recent Covid-19 pandemic for which the same warn app was utilised. This effect is commonly referred to as alert fatigue (Potter et al., 2018; Roberts et al., 2022). Another participant who did not take warning seriously mentioned that when the flood arrived, the person tried to react but gave up at some point. Experiencing the flood and the regret has triggered that the person would take warnings more seriously and take different actions next time. This learning from floods is very common and acknowledged in research (Carone et al., 2019; Köhler et al., 2023; Kuang & Liao, 2020; Kuhlicke, Masson, et al., 2020).

6.3.2 What don't we regret?

Despite the many regrets that are summarised above, a few participants clearly stated that they did not regret anything about their actions.
As surprise and stress situations can cause reflexive behaviour, it is important to be psychologically prepared to stay calm (APS, 2018). One participant mentioned that they were worried but managed to stay calm despite the fact that they would have liked to evacuate if they had received warning.

> *'We were somewhat worried but kept calm. Had we known beforehand that it would be much worse than predicted, we would have left our home.' (Original: 'Wir waren schon etwas besorgt, aber haben Ruhe bewahrt. Hätten wir vorher gewusst, dass es viel schlimmer wird als vorhergesagt, hätten wir unser Heim verlassen.')*

Another participant highlighted that acting very prudently was not to be regretted.

> *'Actually nothing, I proceeded very prudently, however, prior information from the municipality would have been helpful.' (Original: 'Tatsächlich nichts, ich bin sehr besonnen vorgegangen, allerdings wäre eine vorherige Information seitens der Gemeinde helfend gewesen.')*

This quote also reflects an earlier finding that people did not claim any regrets on the actions they took unless they (almost) had negative outcomes. Reversing this finding, it can be assumed that all actions that were taken somehow improved the overall outcome or at least did not have any negative effects. Furthermore, taking actions can avoid the regret about failing to do something. It can be related to a statement from another study 'at least doing something' (Nalau et al., 2021) meaning that doing something is better than doing nothing. The preparedness actions taken by participants were not regretted; thus, they can be categorised as no regret actions which are better than inaction.

No regrets were expressed by participants who stated that they have done everything they could do within their (perceived) abilities to act and self-organise (Kievik & Gutteling, 2011).

> *'Tried to stop it, saved the most important things, then saved myself.' (Original: 'Versucht es aufzuhalten, das Wichtigste gerettet, dann selbst gerettet.')*

> *'Packed things, brought family, neighbours, and friends to safety.' (Original: 'Sachen gepackt, Familie, Nachbarn und Freunde in Sicherheit gebracht.')*

Helping others to prepare, evacuate, or similar was one major aspect which was not regretted by participants. Helping others was also one action that was taken by many

participants, in general. Interestingly, even if these actions may have caused a threat to the person's own life, they were not regretted. This helping behaviour and not regretting it may be explained by different psychological backgrounds such as anticipating the guilt of not having helped someone in need, because it may bring us pleasure to help others, or because we have a moral responsibility to help others (Erlandsson et al., 2016).

> *'But I was also standing up to my chest in water to get people out. I would do that again.'*
> *(Original: 'Aber ich stand auch bis zur Brust im Wasser um Leute da raus zu holen. Das würde ich wieder tun.')*

Contrarily, some participants believed that they could not have done anything to prepare for an event like the one in July 2021, and that it is only possible to respond reactively.

> *'That's the force of nature, one can only react.'*
> *(Original: 'Das ist Naturgewalt, man kann nur reagieren.')*

In contrast to the above quote, intended behaviour changes and taken measures imply that the flooding experience evoked a more proactive mindset. Increasing risk awareness and learning from flooding is a common process building on the reflections of past events (Kuang & Liao, 2020; Kuhlicke, Masson, et al., 2020). In this regard, it was mentioned that it is important to have a plan for actions to be taken in emergency cases which can be an easy step towards preparedness.

> *'Create an emergency plan and then execute it.'*
> *(Original: 'Einen Emergency Plan erstellen und dann durchführen.')*

Having an emergency plan and drills are considered stronger preparedness actions and, simultaneously, present proactive actions that can be implemented any time even without an imminent hazard (Katsikopoulos, 2021; Marchau et al., 2019).

6.4 Conclusion

This study explored the flooding event in Germany in 2021 from the perspective of regret to gain a deeper understanding on citizens (no) regrets on disaster preparedness actions to derive lessons learnt towards long-term preparedness actions. In this study we analysed what was regretted (or not) and identified reasons that led to the regret. The results of this study suggest the following implications for disaster preparedness.

Firstly, short-term emergency measures are valuable but long-term preparedness is more important. Participants used various emergency measures to prepare their home in a hurry. These actions were referred to as weak actions (Katsikopoulos, 2021), but not useless as none of the participants regretted having taken those. However, more awareness needs to be raised on the fact that taking these measures in the very last-minute such as preparing the basement when flood water is already intruding, can pose a threat to life and therefore, could become regrettable. In the sense of 'at least doing something' (Nalau et al., 2021), taking actions was not regretted as people perceived that they did (everything) what they could. In contrast, citizens regretted their inaction because they sort of failed to do things they could have done, but there was not enough time. Overall, the results highlighted the need to take the following actions in advance – basically from today onwards: developing an emergency plan including evacuation scenarios, learning to understand the environment better to be able to spot changes or to know what forecasted values will be like in reality.

Secondly, actions need to create a feeling of awareness, responsibility, and independence. Citizens were greatly dependent on authorities in this flooding event (Ommer, Blackburn, et al., 2024). This dependency and their trust in authorities to manage the flooding caused great regrets when the expectations were not met, and this created a difficult situation for the participants. This is a common issue also in other countries i.e., in the UK (Cologna et al., 2017; Thorne, 2014). To anticipate these impasses citizens were in, and to avoid increasing distrust in authorities, actions should support the creation of awareness on risks, build environmental knowledge, and loosen dependencies of citizens while increasing their feeling of responsibility.

Thirdly, long-term preparedness needs to integrate actions that increase the psychological preparedness of citizens. A few participants showed that staying calm in this kind of stress situation where the water is imminent, it is very important to take decisions and not just act reflexive or in panic (APS, 2018).

Fourthly, actions need to be within the capabilities of citizens. The results showed that citizens have taken actions that were within their abilities and in some cases had to give up. Therefore, actions need to be easy-to-implement.

Lastly, many actions that were taken in advance of the flooding were focusing on helping others in various situations and people did not regret this even if their own life was at risk. This finding acknowledges the importance of supporting family, friends, neighbours, and even unfamiliar people. In response to this finding, individual long-term preparedness could be enhanced by focusing on collective action.

Summarising the above findings, it was highlighted that citizens need to be motivated to take long-term preparedness actions in order to cope with future (unexpected) hazards and their impacts. The findings of this study suggest that the no-regrets approach could be a suitable framework combining emergency preparedness and, foremost, long-term preparedness due to the robustness of actions in different scenarios, the no regret factor in case no hazard may be happening, and its motivational elements. However, in addition to the introduced characteristics and to ensure actions are taken and not regretted, the findings of this study showed that no-regrets actions must be easy-to-implement; thus, citizen are able to take them and support the idea of collective action as a motivational and enhancing factor for individual preparedness and self-responsibility, respectively.

Overall, this study has highlighted that regret and the experience of a flood can increase future preparedness which is responding to a large amount of findings from other studies. Yet, the question is whether we really need to experience and regret flooding first before starting to consider long-term preparedness? The no-regrets approach can pave the way towards long-term preparedness of citizens, but more research is needed on how to facilitate citizens walking this way.

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7 Being prepared for an uncertain future with no-regrets: A framework for individual and collective disaster preparedness actions

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Abstract. Why should we prepare for a flood which might never happen? Whether the uncertainty is deep or low, it is certainly not always a motivational factor for citizens to prepare for potential future disasters. Uncertainty has a great influence on decision-making and action taking. To anticipate the resulting inaction, the no-regrets approach was adopted across disciplines to support decision-making under uncertainty. For instance, the approach was adopted in climate change policymaking decades ago. However, it has not been utilised to promote individual disaster preparedness yet. As disaster unpreparedness remains a challenge, we tailored the no-regrets approach to individual but also collective disaster preparedness. As part of this developed framework, various actions were identified for flood preparedness and could be classified within four levels of uncertainty (from deep to low). The review performed in this paper highlighted that most no-regrets actions can be taken in a long-term perspective; thus, starting from today under deep uncertainty. The identified actions unveiled the shortcoming of actions for psychological preparedness. Furthermore, the review showed a bias towards actions for developed countries. In response to the latter finding, a crowdsourcing campaign was designed to extend the list of no-regrets actions suitable for different places and people around the world. The framework and action list can be used as a starting point to promote individual and collective disaster/flood preparedness, while the paper underlines that the uptake of these actions needs to be facilitated by practitioners, local authorities, first responders, or within communities themselves.

Key words: Climate Change Adaptation, Sustainable Development, Disaster Risk Reduction, Psychological Preparedness, Imagination

7.1 Introduction

When a flood enters into our home, we are trapped in a situation where we have to take quick but effective decisions on last minute preparations. Effective disaster preparedness relies on people taking informed decisions in advance of a threat (UNDRR, 2022). However, in reality, we (as citizens) tend to start preparing when a flood is forecasted and very likely to happen, but not any earlier unless we may have experienced flooding before (Kuang & Liao, 2020; Marchau et al., 2019). The dilemma is that long-term preparedness can support us in decision-making and action taking in emergency cases, but who prepares for a flooding event when it is uncertain whether it happens this year, in 48 years, or when we might actually never be affected by it?

The background. Uncertainty is a well-known barrier to decision-making and action taking. For instance, looking back to the 90s, the uncertainty around how the climate would change challenged mitigation policymaking because it was difficult to know for which future the policies should be designed for (Fernau et al., 1993; Plume, 1995). In response to this, it was manifested that uncertainty shall not be used as an excuse to not take decisions or actions (Rio Declaration 1992 (A/CONF.151/26)). Hence, the no-regrets approach was adopted from other research disciplines as a solution for preparing different pathways in an uncertain future (Plume, 1995); thus, taking actions that will not be regretted in any future climate scenario (Heltberg et al., 2009).

The no-regrets approach aims to bypass the potential psychological barrier of regret which is a feeling that we often link to an unpleasant outcome of a decision or action. Additionally, we regret having missed the chance to take an action, and then start imagining what we could have done differently (J. Feldman et al., 1999). When taking decisions (without rush), we commonly evaluate the potential outcome(s) to reduce the possibility of regret. Furthermore, we tend to decide on actions that are not costly, and which may even entail some (co-)benefits. This way, we are less likely to regret taking a decision or action, even if no hazard ever occurs (Heltberg et al., 2009; Sunderrajan & Albarracín, 2021).

The need. Throughout its history, the no-regrets approach has evolved into a ‘unifying lens’ for mitigation and adaptation but also includes risk management, and vulnerability reduction (Heltberg et al., 2009). The approach enhances the idea of

proactive behaviour, shifting away from defensive and reactive disaster management (UNISDR, 2015).

The adoption of proactive behaviour by citizens remains a challenge in disaster management, for instance, because citizens are not aware of risks (Kievik & Gutteling, 2011; Surminski & Thieken, 2017), they may not take a flood risk seriously due to high uncertainty (Hamilton et al., 2020; Ommer, Kalas, et al., 2024), they simply cannot imagine that flooding will happen in their neighbourhood (Ommer, Neumann, et al., 2024), they do not want to invest into something that might never happen (Entorf & Jensen, 2020), they do not see it as their responsibility (Ommer, Blackburn, et al., 2024; Snel et al., 2021), or due to several other reasons. Hence, many citizens are not ready when a flood strikes, especially, if it occurs unexpectedly. Citizens' unpreparedness as well as the unexpectedness of some hazards often cause stress to them resulting in panic, not knowing what to do, or the feeling of being powerless (Bubeck, Botzen, Kreibich, et al., 2012; Thieken et al., 2023). In many cases, this unexpected and stressing situation leads to inaction, hence, longer-term preparedness for a potential flood is important to be able to better cope with a hazard and take valuable actions (Ommer, Kalas, et al., 2024). Taking strong preparedness actions such as developing a household emergency plan or planning last minute (weak) actions such as reparking the car on higher grounds will not only enhance our physical preparedness but also increases our psychological preparedness (Every et al., 2019; Katsikopoulos, 2021).

Perhaps nobody is keen to take actions for something uncertain, especially if these actions are costly (Entorf & Jensen, 2020). For this reason, no-regrets actions with its characteristics (i.e., robustness in different future scenarios, of low or no cost, entailing benefits) can be a valuable approach to promote our long-term preparedness by increasing our knowledge and capacities to cope with and recover from hazards (Ommer, Kalas, et al., 2024).

To date, the no-regrets approach for citizens has not been explored in depth. Heltberg et al. (2009) developed a framework tailoring the no-regrets approach to human vulnerability. Even though they provide potential interventions from household to international level, the framework stays at a conceptual level of vulnerability reduction primarily from a macro-perspective and does not specify criteria for nor concrete examples of no-regrets actions that can be applied by citizens themselves.

The objectives. Recently, it was highlighted that citizens need to be guided and pointed at potential actions and therefore, a practical guidance needs to be developed on how to prepare for different (unexpected) hazards (UCL, 2023). To fill this gap, this paper will introduce a novel framework to guide citizens' disaster preparedness under uncertainty with no-regrets actions. In support of this, this paper will firstly, define criteria for no-regrets actions for citizens based on existing no-regrets literature. Secondly, following the framework's criteria, various flood preparedness actions will be collected and then allocated to different levels of uncertainty. The framework and actions list can assist citizens and citizen groups in taking action under uncertainty about the future. Considering that the collection of disaster preparedness actions, in general, would go beyond the scope of this paper, the focus was set on flood preparedness. However, the framework could be applicable for selecting actions for other types of hazards.

The following Section 7.2 will introduce the review process which was performed to develop no-regrets criteria for actions and to identify no-regrets actions according to these criteria. The framework is introduced in Section 7.3.2 and a no-regrets actions for flood preparedness are presented in Section 7.3.3. Section 7.4 will discuss the framework and identified actions.

7.2 The review

A systematic review of no-regrets literature was performed which highlighted a lack of studies focusing on no-regrets actions that can be performed by citizens. Therefore, the review strategy was adjusted and hence, scoping review was performed to identify criteria that characterise no-regrets actions at different levels (other than the individual level). Acknowledging that actions may not be labelled as no-regrets (Woodruff, 2016), the next step focused on an integrative literature review (including scientific literature, reports, and other literature) to collect actions which fall into the no-regrets criteria identified with the scoping review.

Defining no-regrets criteria. In a first step, a scoping review was performed to identify relevant literature in the context of the no-regrets approach. The databases Web of

Science and Scopus were searched with the key word ‘no-regrets’ in combination with ‘climate change’ and ‘disaster’. In total, 71 no-regrets related papers were reviewed to gain a holistic overview on the different criteria that frame the no-regrets approach. These identified criteria are introduced and discussed in Section 7.3.2.
In addition, the review indicated that the no-regrets approach is primarily addressing international, (sub)national, and community levels. Whereas the research is primarily focusing on policymaking or local adaptation strategies. Looking at the article publications by year, the approach had several peak seasons (1996, 2004, 2009, and 2016) which could perhaps be related to different global events such as the Rio Declaration in 1992 or the COP21 in 2015.

Identifying no-regrets actions. The review of preparedness actions was performed in an integrative manner by performing searches in Google Search, Google Scholar, and the databases Web of Science and Scopus with terms such as ‘emergency measures’, ‘adaptation actions’, ‘adaptation measures’, ‘adaptation interventions’, ‘resilient measures’, ‘robust measures’ in combination with one of the keywords ‘flood*’, ‘individual’. ‘citizen*’, or ‘collective’. The review included different types of literature such as research studies, review papers, reports, and similar. From the literature, actions were selected which fulfilled the no-regrets criteria as framed in Section 7.3.2. The review further identified actions which fulfilled most but not all criteria, and which could be argued to be non-regrettable or of low regret. All identified actions are enlisted in Appendix 3 while Section 7.3.3 provides a summary of these actions linking them to different levels of uncertainty.

7.3 The no-regrets framework for individual and collective disaster preparedness under uncertainty

This Section will outline the no-regrets framework for citizens to support their flood preparedness. The framework firstly, provides background knowledge base (Section 7.3.1), secondly, defines no-regrets criteria which actions shall fulfil (Section 7.3.2), thirdly, introduces specific no-regrets actions that can be taken under various levels of uncertainty (Section 7.3.3), and lastly, limitations of the no-regrets framework are mentioned (Section 7.3.4).

7.3.1 The background

Before delving into the framework, an introduction to uncertainty and the no-regrets approach is provided to build a knowledge base for the framework.

The uncertainty. In plain language, uncertainty reflects that something is unsure (Cambridge Dictionary, 2024). This uncertainty often arises from the fact that we do not have sufficient information about something (van der Keur et al., 2016). A typical example may be climate change where we do not have enough information on how the climate will actually be changing. In addition, the uncertainty around 'unforeseen events' (Adler et al., 2000) can challenge our (long-term) preparedness motivation (Grothmann & Reusswig, 2006; Yusoff & Gabrys, 2011). In the latter, the uncertainty may be related to where and when a hazard might occur, the frequency and magnitude of its occurrence, its impact, or its cascading hazards (Abunnasr et al., 2015). In the context of decision-making, uncertainty is categorised into the following four levels (Marchau et al., 2019; Walker et al., 2003):

- Level 1: low uncertainty with a clear enough future
- Level 2: alternative probable futures
- Level 3: plausible futures/scenarios
- Level 4: deep uncertainty which sometimes refers to an unknown future

The evolution of no-regrets. Back in the 90s, the no-regrets approach was introduced to overcome climate change inaction due to (back then deep) uncertainty which resulted from a lack of scientific evidence (Fernau et al., 1993; Plume, 1995). During this time, the no-regrets approach was adopted to support climate change mitigation policymaking. In the first decade of the 21st century, the idea of no-regrets was widened to adapt to different plausible future climate scenarios (which were developed by then); at the same time, the focus shifted from climate change mitigation to adaptation, for instance by reducing vulnerability and fostering a sustainable development. More specifically, the approach was explored in the adaptation of infrastructure (Auld et al., 2006; Hallegatte, 2009), human vulnerability (Heltberg et al., 2009) and environmental approaches such as water basin management (Barrios et al., 2009), or in agricultural discourses (Tingem & Rivington, 2009). During the second decade, the no-regrets approach shifted towards conservation strategies (Carvalho et

al., 2011; Geyer et al., 2015) linked with climate change mitigation (Crusius, 2020). More recently, the no-regrets approach focuses increasingly on planning with Nature-based Solutions (Castelo et al., 2023; Debele et al., 2023). Simultaneously, the European Commission recognises the need for no-regrets actions to prepare in advance for unfamiliar risks and impacts of disasters at national but also at individual level (HORIZON-CL3-2022-DRS-01-02).

7.3.2 The no-regrets criteria

The well-known secret of the no-regrets approach is to accept uncertainty as far as possible; thus, it is not stopping us from preparing (Auld et al., 2006; Penning-Rowsell & Korndewal, 2019). Doing this, we are not only preparing for one, but several different futures. For instance, having a household emergency plan for several flooding scenarios will help us to take better decisions in the case of an approaching flood. We will probably not regret having an emergency plan if flooding never happens (Nalau et al., 2021). Hence, the main idea of the approach is that we take actions that we will not regret because, according to existing literature, no-regrets actions shall be 1) *robust* in the sense that they are suitable for difference future scenarios and are targeting the reduction of risks (Anderson et al., 2022; Woodruff, 2016) but, at the same time, they are *flexible* and can be adjusted (Nalau et al., 2021); 2) of no or low *costs* which can be outweighed by their *effectiveness* and *co-benefits* to our environment, society, and economy (IPCC, 2012); and 3) *easy-to-implement* with least effort and material (Anderson et al., 2022; Smith et al., 1996). In the following, each of the above listed no-regrets criteria is introduced in more detail.

Robust but flexible. Actions shall be robust in different scenarios under uncertainty but also flexible in the way that they are adaptable to the future reality (Dilling et al., 2015; Hall & Solomatine, 2008; Smith et al., 1996).

For instance, a flood emergency plan can be designed integrating different hazard scenarios (flood return periods) or self-observed rainfall thresholds. However, this emergency plan needs to be robust in each of these future scenarios. Therefore, it may not be possible to develop the best plan (because it might never suit all scenarios) but rather to make it satisfactory for all potential storylines (Sayers et al., 2012). For the

decision on the most suitable robust action(s), we are evaluating different criteria i.e., its costs, effectiveness, benefits, or its flexibility (Mei et al., 2018; Postek et al., 2019). With a changing climate, it is likely that i.e., flooding probabilities might change, therefore, an emergency plan (or other actions) also needs to be flexible. Hence, if flooding probabilities change in the future, we review the robustness and suitability of our actions and then perhaps adjust them.

Economically cost-effective. The costs of actions are playing a major role in the definition of no-regrets actions as they are often promoted with their low or no costs. There are multiple barriers to action which are summarised as the 'dragons of inaction' (Wang et al., 2022) and costs are one of them. For instance, the willingness-to-pay for flood preparedness measures was evaluated to be around 50€ in Germany, whereas citizens with flood experiences are more likely to implement them (Entorf & Jensen, 2020). In fact, no-regrets actions (strategies, options) are not only considering costs but rather look at them in combination with the effectiveness or efficency of an action to reduce flooding or damages (Anderson et al., 2022; Smith et al., 1996). Therefore, this framework will not exclude actions that are of higher cost if they are more effective in flood impact reduction than other actions. However, these actions could be considered as low-regret actions.

The (co-)benefits. Another commonly acknowledged characteristic of no-regrets actions are its potential (co-) benefits which should be given in all scenarios. (Co-)benefits may be perceived as a reward and function as an extrinsic motivation (Lewis et al., 2016). There are two different types of benefits: direct benefits (simply referred to as benefits) and co-benefits which describe positive side effects of an action (Ommer et al., 2022). For instance, a benefit of a Nature-based Solution such as a green roof is the reduction of flooding because of its water retention ability and an indirect benefit (co-benefit) is the enhanced biodiversity value also provided.
No-regrets actions can have various environmental, social, and economic co-benefits: from a broader perspective, no-regrets actions can benefit building resilience and adaptive capacity, reducing vulnerability, sustainable development, environmental protection, or avoided damages (Baills et al., 2020; Hallegatte, 2009; Heltberg et al., 2009). In more detail, (co-)benefits are i.e., informed decision-making,

socialising, or financial stability (Le et al., 2023). Moreover, there may be co-benefits linked to policy instruments i.e., insurance incentives (Botzen, 2019). These (co-)benefits can be effective immediately or a bit delayed, but they shall be of long-term no matter which scenario (Ommer et al., 2022).

However, (co-)benefits are not always perceived as highly important. For instance, Nature-based Solutions are primarily promoted with their co-benefits, but a study found that cost-effectiveness was ranked more important by local citizens than the co-benefits of the solutions (Anderson et al., 2022). Therefore, this framework includes actions that may not have obvious co-benefits but may be suitable because they are easy-to-implement and not regrettable.

Easy-to-implement. Besides the commonly communicated characteristics (robustness/flexibility, cost, and benefits), actions need to be easy-to-implement to encourage engagement and uptake by citizens (Smith et al., 1996). Actions are commonly selected based on e.g., their benefits or their cost-effectiveness and each in combination with what was easiest to do. Easy-to-implement can be understood as an action which does not require a lot of material, effort, knowledge, or capabilities. The capability to take an action is also one major enabler for preparedness behaviour (Kievik & Gutteling, 2011). This so-called self-efficacy further builds on the person's belief to be able to act (Wang et al., 2021).

Collective. A final optional addition to the no-regrets characteristics is the idea of taking actions together with neighbours, family members, friends, etc. The connectedness of citizens, social norms and culture can motivate individuals to take collective actions and also increase their self-responsibility (Adger, 2003; G. Feldman & Albarracín, 2017; Kuang & Liao, 2020; Soetanto et al., 2017). Moreover, collective actioning can leverage into bottom-up initiatives which can function as a bridge between citizens and local authorities (Geaves & Penning-Rowsell, 2015; McEwen et al., 2018). Continuous engagement and collective visioning can, in turn, increase individual action (Gaillard, 2010; Soetanto et al., 2017). For these reasons, this framework does not only consider individual actions but also encourages collective actions.

7.3.3 The no-regrets actions

The review on flood preparedness actions for citizens was performed in accordance with the criteria developed in the previous section which resulted in a long list of no-regrets actions attached in Appendix 3.

The identified actions could be classified into actions that would be best to take in a long-term perspective (starting from today) or in a short-term perspective (e.g., when a flood forecast was issued). Adding the uncertainty component, the previously introduced four levels of uncertainty could be related to different levels of threat and long or short-term actions. These proposed four levels of disaster preparedness under uncertainty (Figure 8) are introduced below along with a summary of the suitable no-regrets actions for each level.

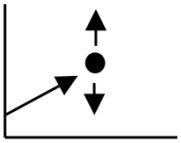
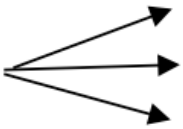
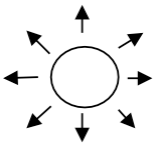
Level of uncertainty	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Uncertainty	A clear enough future 	Alternative futures (with probabilities) 	Plausible futures/ scenarios 	Unknown future 
Time	Hazard warning issued	(Medium-range) forecast indicating a probable threat	Aware of local risks (e.g., flooding)	Today (unaware of risks)
Disaster preparedness	Short-term preparedness		Long-term preparedness	
No-regrets action focus	Damage mitigation, coping capacity		Awareness raising, gaining knowledge, building coping capacities, reducing vulnerability, hazard mitigation	

Figure 8: Disaster preparedness under uncertainty (adapted from Marchau et al., 2019)

In more detail, the four levels of disaster preparedness under uncertainty are:

Level 4 (Unknown future). *Uncertainty*. This level is often referred to as deep uncertainty meaning that we do not know how the future looks like as there are uncountable different scenarios. This level also includes disasters ranging from more common hazards such as flooding to unknown hazards. *Time*. Anytime – not related to a specific event. *Disaster preparedness*. As we don't know which events will be happening in the future, long-term preparedness is needed to focus on gaining knowledge on potential scenarios and building capabilities to cope with (surprising) emergency situations. *No-regrets action focus*. Gaining knowledge on local hazards,

risks, disaster management, and early warning; developing emergency response capabilities; connecting with other citizens and communities; increasing awareness, imagination, and action on climate adaptation; observing the weather and environment to develop local thresholds; enhancing psychological preparedness for emergencies; and considering economic preparedness.

Level 3 (Plausible futures). *Uncertainty*. In this level, we are aware that we are living in a hazard risk area but there is a great uncertainty around the timing, magnitude, and impact of a hazard which can be formed into different scenarios (i.e., flood return periods). *Time*. Anytime – after becoming aware of the risk. *Disaster preparedness*. Based on these scenarios different long-term preparedness actions can be taken to reduce the risk. *No-regrets action focus*. Founding action groups; raising awareness within your community; assessing local disaster risk; reducing disaster risk with Nature-based Solutions; increase collaboration in risk management between the community and local authorities; developing community emergency plans and practices; ensuring individual economic preparedness; increasing property resilience; and stocking up of emergency resources.

Level 2 (Probable future). *Uncertainty*. The hazard occurrence is probable but there might be an alternative future. Uncertainty might be related to the timely or spatially manner of the hazard, or to its impact. *Time*. Days or weeks before a hazard strikes. *Disaster preparedness*. As a hazard is becoming likely, short-term preparedness is starting (e.g., implementing emergency measures). *No-regrets action focus*. Preparing the home and garden for potential water intrusion; setting up an evacuation plan and kit; and raising awareness on the probable hazard within your community.

Level 1 (Clear enough future). *Uncertainty*. Weather forecasts provide a clear (enough) prediction about the approaching hazard; thus, the uncertainty about the hazard is low. *Time*. Hours up to few days before the hazard strikes. *Disaster preparedness*. Due to the imminent hazard, actions should be focusing on preparing for response and recovery. *No-regrets action focus*. Last preparations such as placing sandbags; installing pumps; switching off gas, etc.; or reparking the car.

7.3.4 The limitations

The no-regrets approach is not always as promising as it seems at first glance. Throughout the years, several limitations were highlighted which include 1) the claim that the no-regrets approach presents an over-optimistic strategy (Dilling et al., 2015); 2) that over-presenting (unquantified) co-benefits may cause distrust in the solutions if they do not always apply (Anderson et al., 2022); 3) decision-making and action taking may be further limited by limitations of imagination of different future scenarios (Ommer, Neumann, et al., 2024); and 4) action taking is not only triggered by the value of this approach but depends on many factors such as citizens awareness of risk, their attitudes towards climate change, social trust and norms as well as gender, age, education, or feeling of responsibility (Mata et al., 2023).

7.4 Towards disaster preparedness under uncertainty

The aim of this review paper was to tailor the no-regrets approach to citizens' disaster preparedness under uncertainty in form of individual or collective action. For this purpose, a literature review was performed to define the characteristics of the approach and adjust them to citizens. The second objective was to identify no-regrets actions that can guide individual and collective flood preparedness. The literature review for developing the framework and gathering no-regrets actions highlighted several limitations and considerations around the no-regrets approach and disaster preparedness which are discussed in the following.

Thinking long-term. Most actions that were identified are actions that can be taken today even when the occurrence of hazards is deeply uncertain. In fact, the majority of actions are long-term which means that they can be done once and then persist (in contrast to single-use actions (e.g., reparking the car before a flood)). These long-term actions are robust for different scenarios but also flexible; thus, they can (or must) be adjusted in the future. For instance, the flood risk maps in Europe (developed in line with the EU Floods Directive 2007/60/EC) are updated every few years; thus, our understanding of flood risk areas needs to be adapted also with these updates or personal experiences. The identified long-term actions increase our knowledge and enhance our capabilities to cope with and recover from a disaster. Whereas short-term actions are primarily focusing on damage mitigation.

Besides uncertainty, one barrier to long-term preparedness is our imagination of potential threats (Ommer, Neumann, et al., 2024). Experiencing a flood can help us to imagine it in the future (at least as severe as we have experienced it) because we can draw on our mental imagery (Nanay, 2021). However, when we cannot draw on this mental imagery, visualisations may help us to imagine. For instance, to foster the depiction of a disaster in our mind, tools of digital visualisations (e.g., virtual reality, digital twins, or augmented reality) are increasingly adopted in disaster research i.e., for flood risk management (Bakhtiari et al., 2024). Moreover, exercises such as future visioning (Nalau & Cobb, 2022; Sevilla et al., 2023), methods of storytelling (Finn et al., 2023; Shepherd et al., 2018; Young & Annisette, 2009), or similar could be adopted in i.e., workshops to cultivate imagination for long-term preparedness.

A question of place and people. The identified actions from various areas around the world highlighted that actions may be different depending on the place. For instance, a study showed that, in India, citizens are keeping ropes to build boats from banana leaves for evacuating flooded areas (Oliver et al., 2023). This type of action may not be considered as suitable or feasible in other countries. Another example are flood insurance mechanisms, flood maps, or general advice on flooding which may not exist in every country around the world yet.

The point is that no-regrets actions shall prepare citizens for potential future hazards by strengthening their knowledge and capabilities. Since every place, community, and individual may have a different starting point and therefore, actions need to be selected based on their suitability for the area and citizens. Also acknowledging that people may regret different decisions and actions; thus, some actions may be regretted by some people while others are not (Dilling et al., 2015; Hallegatte, 2009). From a community perspective, it is important to decide on actions together to also enhance the feeling of responsibility and ownership of these actions (IUCN, 2014).

Crowdsourcing no-regrets actions. The identified actions do not present a holistic list. This is primarily caused by the diversity of names for actions (e.g., emergency measures or adaptation interventions) which challenged the review and collection of actions. To circumvent this limitation, the list of no-regrets actions was transformed

into a crowdsourcing tool which enables this current list to grow continuously[3]. In the sense of crowdsourcing, this tool allows any user to add more actions that fall under the framework's criteria. This shall encourage the collection of indigenous, local, and traditional actions from all over the world. Furthermore, the crowdsourcing solution is not limited to flooding but encourages the adding of actions for different hazards as well as different phases of disaster management.

Psychological preparedness?! Many no-regrets actions have potential co-benefits for our mental health before, during, and after a disaster but direct actions to deal with the psychological effects of disasters are lacking.

The majority of the identified actions are targeting the physical preparedness by focusing on reducing damages to our home and ourselves. Even though, having an emergency plan may ease decision-making in an emergency situation, we are probably not psychologically prepared for dealing with the situation (Every et al., 2019). Only a few actions were found on how to deal with our emotions, especially, stress in these situations.

Our behaviour in emergency situations varies likely from our 'usual' behaviour and therefore, it is important for ourselves to understand how we can act in and cope with these situations (Canadian Red Cross, 2024; Höfler, 2014). For instance, how do we act in stressful situations and how can we cope with them?

An example for a psychological preparedness action is the AIM method (APS, 2018) which includes the following three steps: 1) Anticipating our psychological reactions by preparing ourselves emotionally that a hazard might be happening and that it might be stressful; 2) Identifying our feelings (e.g., racing heart, shortness of breath) and thoughts (e.g., I cannot do anything) that we have in a stress situation; 3) Managing how we will acknowledge that we are stressed and how to respond to it.

Moreover, mental health impacts from experiencing disasters are increasingly recognised. For instance, flooding may cause distress due to the disastrous flooding impact, anxiety, or even depression (Stanke et al., 2012). Hence, we need to learn how we anticipate post-disaster mental health impacts (Makwana, 2019).

[3] https://citizens4climate.com/crowdsourcing/campaigns/229/responses/add

Ticking all the boxes? The selection of no-regrets actions was performed by ticking that each of the no-regrets characteristics as defined in the framework is given. Yet, some actions were included which do not fulfil all criteria but may not be regretted or regret may be low. These actions can be costly, do not have obvious co-benefits, or are not easy-to-implement:

- Several actions were found to be of higher economic costs such as installing flood barriers, creating green roofs, or similarly. The fact that they are of high costs should have excluded them. However, in this framework, costs are not considered solely but in combination with their effectiveness. This may often be the case for increasing building resilience or Nature-based Solutions (e.g., green roofs). For the first case, these actions may not be regretted because they are very efficient in damage mitigation. Similarly, for Nature-based Solutions, it could be argued that they are more efficient in terms of flood mitigation but, additionally, they can entail many co-benefits, but to which extent is often unknown.
- Similarly, some actions may not be easy to be implemented (e.g., because it can be difficult to motivate for collective action), do not have co-benefits, or are not of a collective character. However, their effectiveness in hazard reduction or damage mitigation could be argued to outweigh the lack of some no-regrets values.

Hence, actions falling in the above explained categories were integrated into the action list but shall be referred to as low-regret actions.

What about motivation? The shift from reactive to proactive behaviour does not only include action taking but also implies a behaviour change (Abunyewah et al., 2018). According to the COM-B theory on behavioural change (Michie et al., 2011), it takes capabilities, opportunities, and lastly, motivation to change. In this framework, no-regrets actions shall be easy-to-implement. Not having this criterion would mean that perhaps many people would not be capable of taking these actions which would directly limit the likelihood of change.

However, even if people are capable of taking no-regrets actions it does not mean that they will take them because they are missing the opportunity or lacking motivation (according to the behaviour change theory). Therefore, this paper acknowledged that

it is not enough to build this framework and list possible actions but the next (and probably most important) step – in practice – would be to facilitate their uptake by creating opportunities and increasing people's motivation.

In terms of motivation, this framework aimed to approach the motivational factor with the criteria of cost-effectiveness, co-benefits, and foremost, the collective actions. Whereas cost-effectiveness and co-benefits may be perceived as rewarding (extrinsic motivation), collective action may intrinsically enhance individual action motivation and self-responsibility (L. S. Morris et al., 2022).

It can be summarised that the uptake of no-regrets actions needs to be facilitated, for instance, through gamified tools, policy instruments, community actions, or similar. This facilitation needs to focus on creating opportunities and increase motivation. Finally, it shall be acknowledged that behavioural change can be stressful for people; thus, it needs to be further considered to improve psychological resilience at the same time (Adams et al., 2021).

A sneak into the future. This review on no-regrets actions for citizens underlined the need for further research but also primarily application in practice. A systemic review showed that the no-regrets approach was not specifically supporting individual action. However, a large number of disaster preparedness actions could be identified which can fall in the no-regrets criteria but were differently named. Overall, the review of actions underlined the lack of actions for psychological preparedness which are of high importance. Hence, further interdisciplinary research is needed for integrating more psychological research into disaster studies. Moreover, identified actions are biased towards developed countries. To approach this gap, a crowdsourcing campaign was designed which shall invite anyone to add more actions to the current selection. This crowdsourcing campaign is not only focusing on flood preparedness but on individual and collective actions related to all disaster management phases and for different hazards. Most actions identified in this review are applicable for promoting long-term preparedness under uncertainty, yet the greatest challenge for practice is the facilitation of the uptake of these actions. This facilitation shall involve the development of i.e., gamified tools, supporting policy instruments, or leveraging collective action to motivate citizens and to create opportunities for change.

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8 The no-regrets of Nature-based Solutions

The previous chapter indicated that Nature-based Solutions (NBS) can be referred to as no-regrets actions for disaster preparedness under uncertainty due to their potential effectiveness in flood mitigation but also because of their versatile co-benefits. Yet, it was mentioned earlier that co-benefits of NBS are not quantified and thus, the impact of co-benefits remains difficult to grasp. In this regard, this chapter will make a short journey into the discourse of Nature-based Solutions with the aim to provide practical guidance on the pre-assessment of co-benefits to ensure their perceived impact is actually likely.

Utilising the ideas of nature to reduce the risk of hazard, Nature-based Solutions have set a trend in disaster risk reduction (Croeser et al., 2021). This trend is not only ascribed to the fact that they are more natural than e.g., a dam, but primarily to their entailing co-benefits (Anderson et al., 2022; Kabisch et al., 2016; Ommer et al., 2022). These co-benefits are further known to be valid in different future scenarios. Due to this characteristic of NBS as well as the statements that they are robust, flexible, and cost-effective, they are often referred to as no-regrets actions (Debele et al., 2023). The co-benefits of NBS are one of the main selling points (or no-regrets factor) which is used for their promotion at different levels. This may be explained by the idea of reward - benefits being an extrinsic motivation factor (L. S. Morris et al., 2022). However, the point was raised that NBS may sometimes be oversold or have ‘characteristics of green-washing’ (Anderson et al., 2022). This raises the question on how significant these benefits are and what about potential disbenefits?

The following Section 8.1 will introduce the wide range of commonly acknowledged co-benefits of Nature-based Solutions and the (to a lesser extent discussed) potential disbenefits before developing a pre-assessment framework for those in Section 8.2.

8.1 The co-benefits

The term co-benefit was originally introduced as health benefits from climate change mitigation policies (IPCC, 2001). In the context with NBS, the term co-benefit is widely used but lacking a clear definition. Nowadays, co-benefits are not limited to health benefits but encompass a holistic spectrum of unintended benefits ranging from ecosystem to socio-economic and health benefits (Gómez Martín et al., 2020). A large

amount of co-benefit indicators is acknowledged and agreed on in literature (European Commission, 2021; NWRM, 2015a; Raymond, Frantzeskaki, et al., 2017; Somarakis et al., 2019; Wendling & Rinta-Hiiro, 2019; Xing et al., 2017) but potential disbenefits stay largely unmentioned. The following introduces co-benefits and disbenefits identified in research and policy literature.

Air & Noise. Extending or introducing green spaces, especially, in urban areas or along major roads, can reduce air pollution (Abhijith et al., 2017; Hewitt et al., 2020), noise (Baldauf et al., 2008; Kalansuriya et al., 2009), and store carbon dioxide (European Commission, 2015; Pataki et al., 2011). Depending on different design factors, vegetation can either improve air quality or simply function as a barrier when a high leaf density of trees blocks pollutants resulting in higher air pollution rates above the road and low rates in the park (Abhijith et al., 2017; Barwise & Kumar, 2020). On the other hand, NBS such as green buildings can reduce greenhouse gas emissions of the energy sector with their cooling effect on houses. Overall, improved air quality promotes the health of citizens by e.g., decreasing the risk of respiratory diseases (Kumar et al., 2019; Nowak et al., 2014) and allows citizens to gain sleeping quality from reduced noise pollution (Ferrini et al., 2020). Improved conditions ascend property and housing values profiting local tax revenues (Luttik, 2000).

Temperature Regulation. Green urban infrastructure can significantly affect air and surface temperatures through shading and increased evapotranspiration. This effect is varying as, for instance, a water retention pond – primarily targeting flood prevention – can decrease surface temperature during the day but can cause warmer air during the night due to their thermal storage (Solcerova et al., 2019). Reduced temperatures benefit human health and well-being by lowering heat stress and enhancing thermal comfort, respectively (Augusto et al., 2020; Enzi et al., 2017). The cooling effect of vegetation is further used for insulating buildings with green walls or facades (Convertino et al., 2019).

Soil health. Many NBS are directly targeting the improvement of soil quality for DRR, but for some of them it counts as a co-benefit were vegetational covers promote soil conditions in two ways: firstly, by protecting the soil from wind or water erosion, and,

secondly, by improving other soil properties such as soil organic matter and water holding capacity. Increased biomass further enables soil carbon storage.

Water. Blue and green spaces can benefit water availability and quality by enabling storage and filtering pollutants. For instance, wetlands are recognized for their action on purifying water by retaining particles including phosphorus (through slowing water flows) or functioning as a buffer between land and water bodies (Dordio et al., 2008). Similarly, riparian buffers, and other green solutions filter pollutants (e.g., nitrogen and larger sediments) and hinder them from entering surface waters. Overall, wetlands and riparian forests are known to increase biodiversity which, in turn, encourages recreational purposes (e.g., bathing), tourism and, therefore, can improve health and well-being (Oral et al., 2020).

Biodiversity. Blue and green spaces can be strategically implemented to increase habitat quality (including connectivity, size, providing services, and more), restoration or providing services of the habitat that are important factors for species (Liquete et al., 2015; Vallecillo et al., 2016; Zhang et al., 2019). Flora, fauna, and soils constitute a unique system providing services and goods to humans, but they can also be perceived as disservices: in fact, created habitats can entail pollen evoking allergic reactions, disturbing insects such as mosquitos, or transmitted diseases like Lyme from ticks (Lyytimäki & Sipilä, 2009).

Socio-economic Development. Recreational areas enhance relaxation and stress relief (Roe et al., 2013), promote outdoor activities for every age resulting in improved quality of life, physical and mental health (Sugiyama & Ward Thompson, 2007). People are often willing to pay for recreational areas, touristic visits of natural areas (Haase, 2017; Rice, 2019), or apartments and properties near parks (Kolbe & Wüstemann, 2015; Luttik, 2000; Tyrväinen & Miettinen, 2000; UK's Office for National Statistics, 2018). Furthermore, improved air quality, noise attenuation, and climate regulation are aspects that can lead to rising property values (Luttik, 2000; Zalejska-Jonsson et al., 2020). In this context, municipalities can economically benefit through increased tax revenue from higher property prices or tourism. Nonetheless, it is evident that NBS need financing, and this aspect can constitute major challenges (Droste et al., 2017).

However, great concern is raised on the gentrification of areas due to NBS because higher property values can be disadvantageous to lower income households and can provoke social inequalities (Anguelovski et al., 2019; Haase, 2017; Shi, 2020). NBS planning, implementation and maintenance of an urban park can create job opportunities (Maes & Jacobs, 2017). Overall, incorporating the public in the NBS life cycle can raise awareness of NBS itself and related environmental issues, increase social cohesion, or encourage shared ownership of the NBS (Ferreira et al., 2020).

A network of co-benefits. The previous sections introduced common co-benefits and disbenefits by simultaneously explaining their causal relationships. Two types of relationships were identified from the literature review: relationships can be positive (e.g., the creation of an urban park leads to noise attenuation which increases property values) or negative (e.g., increased property prices can lead to social injustice) which can reflect when a co-benefit turn into a disbenefit. Figure 9 illustrates these interrelationships of co-benefits and disbenefit indicators unveiling a complex structure. Following the network paths from left to right, this network shows that some co-benefits and disbenefits are either primarily influenced by blue and green spaces, indirectly through the alteration of a co-benefits or disbenefits (e.g., improved air quality will increase health of local citizens), or even both (directly and indirectly). Lastly, it becomes obvious that the co-benefits and disbenefits are resulting in overarching indicators: health and well-being, biodiversity, and socio-economic development – representing SDGs.

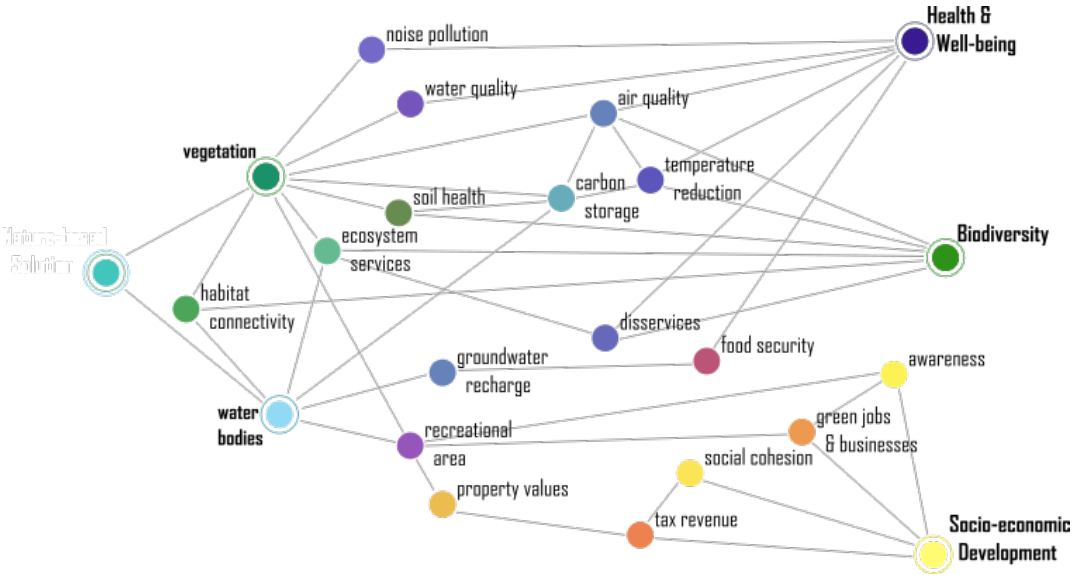

Figure 9: The interrelationships of co-benefit and disbenefit indicators

8.2 Quantifying co-benefits and disbenefits of Nature-based Solutions targeting Disaster Risk Reduction

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Abstract. Nature-based Solutions function as an umbrella concept for ecosystem-based approaches that are an alternative to traditional engineering solutions for Disaster Risk Reduction. Their rising popularity is explained partly by their entailing additional benefits (so called co-benefits) for the environment, society, and economy. The few existing frameworks for assessing co-benefits are lacking guidance on co-benefit pre-assessment that is required for the NBS selection and permission process. Going beyond these, this paper develops a comprehensive guidance on quantitative pre-assessment of potential co-benefits and disbenefits of NBS tackling Disaster Risk Reduction. It is based on methods and frameworks from existing literature around NBS and related disciplines. Furthermore, this paper discusses the evaluation of the quantified results of the pre-assessment. In particular, the evaluation focuses on the significance of change of the estimated co-benefits and disbenefits as well as the sustainability of the NBS. This paper will support decision-making in planning processes on suitability and sustainability of Nature-based Solutions and assist in the preparation of Environmental Impact Assessments of projects.

Key words: Quantification, Co-benefits, Disbenefits, Nature-based Solutions, Disaster Risk Reduction, Environmental Impact Assessment, Pre-assessment, Sustainability

8.2.1 Introduction

Nature-based Solutions (NBS) function as an umbrella term for ecosystem-based approaches. According to the recently universally agreed-upon definition by the United Nations Environment Assembly (UNEP/EA5/L9/REV.1), NBS are 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.' NBS are increasingly adopted for Disaster Risk Reduction (DRR) considering that healthy ecosystems can cope better with occurring hazards and reduce the magnitude, duration, or frequency of hazards (Depietri & McPhearson, 2017; UNDRR, 2021). NBS are further implemented to tackle other societal challenges including climate change mitigation and adaptation, biodiversity loss, and health and well-being (Cohen-Shacham et al., 2016).

NBS are known and promoted for their entailing co-benefits - referred to as positive side effects or unintended effects (Gómez Martín et al., 2020). They gained popularity in the context of climate change as positive side effects of climate change mitigation policies on health and well-being (IPCC, 2001). In the context of NBS for DRR, co-benefits range from ecological to socio-economic sectors assisting global frameworks such as the Sustainable Development Goals (SDGs), the Paris Agreement, or the Convention on Biological Diversity (CBD). However, negative side effects, so-called disbenefits, often remain unmentioned in the shadow of co-benefits. Nonetheless, they are more frequently integrated into decision-making on NBS (Croeser et al., 2021; Gómez Martín et al., 2020).

To date, a broad spectrum of NBS co-benefits and a smaller number of disbenefits were identified and reported within NBS research (European Commission, 2021; NWRM, 2015a; Raymond, Frantzeskaki, et al., 2017; Somarakis et al., 2019; Wendling & Rinta-Hiiro, 2019; Xing et al., 2017) (depicted in Figure 10). Ecological co-benefits are largely representing regulating ecosystem services (Maes et al., 2013) such as the improvement of air, water, and soil quality, climate regulation, and carbon sequestration. While recreational and touristic areas are associated with cultural ecosystem services.

Figure10: Commonly reported NBS co-benefits and disbenefits

Green spaces and the co-design of NBS can further support social cohesion and inclusion (Ferreira et al., 2020). Other co-benefits of NBS can be the attenuation of noise through vegetation or the reconnection of existing habitats benefiting biodiversity. However, some ecological co-benefits may be perceived as disbenefits such as increased pollen in the air or mosquito populations (Lyytimäki & Sipilä, 2009). Moreover, NBS can serve societies and economies by creating job and business opportunities or lowering energy expenses through greened buildings. Overall, NBS, especially in urban areas, can increase the attractiveness of an area leading to boost property prices. In some cases, a co-benefit may cause disbenefits (e.g., a rise in property prices can cause segregation or social exclusion (Anguelovski et al., 2019; Haase, 2017; Shi, 2020)) or a co-benefit may turn (partly) into a disbenefit, for instance, basins can have a cooling effect on the microclimate during the day but a warming effect during the night (Solcerova et al., 2019). Another example is the dense planting

of trees that can lead to a barrier for air pollutants rather than enhancing sequestration (Abhijith et al., 2017). Rising tourism and property prices but also new jobs and businesses can be beneficial for local tax revenues and the overall socio-economic development. Whilst ecological and socio-economic co-benefits and disbenefits are influencing the health and well-being of the citizens. For instance, increased air and water quality but also noise attenuation can have positive effects on health while attractive and recreational areas or regulated temperature boost their well-being. Nonetheless, perceived ecological disbenefits such as pollen or mosquitoes can cause health issues or distress, respectively.

To identify suitable NBS for DRR, NBS are advised to be selected based on their potential to reduce the magnitude, duration, or frequency of the targeted hazard(s) (Liquete et al., 2016; Raymond, Frantzeskaki, et al., 2017) considering their effectiveness in current and future climate (Calliari et al., 2019; Cohen-Shacham et al., 2019; Emilsson & Ode Sang, 2017), with respect to place-based characteristics, perceptions and needs of citizens and stakeholders (Cohen-Shacham et al., 2019; Emilsson & Ode Sang, 2017; Giordano et al., 2020; Kuller et al., 2019). Recent frameworks highlight the importance of integrating co-benefits (and partly disbenefits) in decision-making (Croeser et al., 2021; European Commission, 2021; Gómez Martín et al., 2020; Kuller et al., 2019; Raymond, Pam, et al., 2017). However, the expected impact of co-benefits is communicated only in qualitative terms (e.g., low to high) as their quantification remains a great challenge in NBS research. Quantification is vital to evaluate, firstly, the significance of the potential impact of side effects and, secondly, the sustainability of the NBS considering their contribution towards other societal challenges. Existing NBS co-benefit assessment frameworks (European Commission, 2021; Giordano et al., 2020; Liquete et al., 2016; Raymond, Pam, et al., 2017; Watkin et al., 2019) focus primarily on assessment, monitoring, and post-project evaluation while largely neglecting disbenefits. Hence, guidance on quantitative pre-assessment of co-benefits and disbenefits is urgently needed to answer the following questions to support decision-making in the NBS selection process:

1) How significant is the actual impact?
2) When can co-benefits turn into disbenefits?
3) How sustainable is the NBS in the area of interest?

This paper builds on existing research to provide guidance on quantifying co-benefits of NBS

and on answering the above questions to support decision-making in NBS selection processes. Therefore, in Section 8.2.2, we reviewed existing co-benefit assessment frameworks and quantification methods from NBS literature and related research fields for the co-benefits and disbenefit indicators introduced above. Building on the existing knowledge, Section 8.2.3 presents guidance on the quantification of each indicator to support existing frameworks while Section 8.2.4 discusses the evaluation of the quantitative results to respond to the questions above.

8.2.2 Assessment Frameworks and Tools

This section presents a narrative review of existing co-benefit assessment frameworks and quantification methods from related disciplines. The aim of this review is the identification of methods that can be adopted for the pre-assessment of NBS co-benefits and disbenefits. Table 2 summarises these frameworks and tools introduced in this section along with their focus, assessment type, and approached indicators.

Multiple frameworks and methods for assessing co-benefits were developed within NBS research: Raymond *et al.* (2017) developed a seven stage assessment framework building on the work of Kabisch *et al*. (2016), but remains superficial when it comes to the quantification. Liquete *et al.* (2016) proposed a multi-criteria analysis for assessing co-benefits with emphasis on integrating multiple interests of stakeholders. This framework primarily aims to ease decision-making on NBS based on multiple criteria by assessing different alternatives towards the interests. Watkin *et al*. (2019) targeted the quantification of the rate of change with a scoring approach where co-benefits are classified into five scores from low to high by also allowing negative scores. An issue unravelling here, is the fact that the proposed assessment frameworks are primarily designed for monitoring and post-project assessments; thus, they cannot be directly adopted for the pre-assessment of co-benefits and disbenefits. The indicators incorporated in the frameworks introduced above are covering direct benefits and co-benefits, but do not always separate between these. In the context of climate change mitigation and flood reduction, two tools were developed to estimate and monetise potential carbon storage and air pollution mitigation (i-Tree tool series (USDA Forest

Service et al., 2006)), and sustainable urban drainage systems (Benefit Estimation Tool (B£ST) (Susdrain, 2019)).

On EU-scale, guidance for pre-assessment is provided in context with the Environmental Impact Assessment (EIA) (Directive 2014/52/EU) (Lantieri, Adrien; Lukacova, Zuzana; McGuinn, Jennifer; McNeill, 2017) and within the NBS impact evaluation handbook (European Commission, 2021). The planning of NBS projects incorporates the assessment of potential impact on the environment as new projects must undergo an EIA to receive permission for it. Nonetheless, the guidance on the EIA Directive is neglecting the quantification of indicators. While the NBS impact evaluation handbook (European Commission, 2021) offers guidance on the pre-assessment, monitoring, and evaluation of co-benefits, but specific assessment methods for each indicator are orientated towards monitoring and evaluation – oversighting the pre-assessment.

Also on EU-scale, the ecosystem service assessment framework (Maes et al., 2013, 2020) provides guidance on mapping and assessing the current status of ecosystems (and their services) along with an extensive list of European scale datasets that can assist in finding baseline data. This framework is broadly applied by researchers, for instance, Balzan *et al.* (2021) quantitatively pre-assessed a number of regulating ecosystem services to support the prioritisation of NBS for dense urban areas, while a few cultural ecosystem services were qualitatively estimated by experts using a scoring approach. Their method could be adopted for assessing co-benefits, but pre-assessed co-benefits are limited to air quality, carbon storage, temperature regulation, noise reduction and socio-economic factors. Paracchini *et al.* (2014) aimed at mapping cultural ecosystems in Europe, in particular the recreational potential. The GIS tool InVEST (Natural Capital Project, 2018) was developed for decision-making support by monetizing potential ecosystem service provisions calculated based on land cover types. This tool is applicable e.g., for the assessment of potential impacts from Land Use and Land Cover Changes (LULCC).

The review and Table 2 highlight the fact that pre-assessment of ecological indicators is more commonly practiced than of socio-economic indicators. This phenomenon mirrors global challenges of socio-economic data collection and availability (European Science and Technology Advisory Group, 2019). The following section aims at balancing this difference by suggesting proxies and methods for pre-assessment.

Outputs of the assessment frameworks vary between indicator units (Balzan et al., 2021; European Commission, 2021; USDA Forest Service et al., 2006), monetised values (Natural Capital Project, 2018; Raymond, Pam, et al., 2017; Susdrain, 2019; USDA Forest Service et al., 2006), dimensionless values (Paracchini et al., 2014) or scores (Watkin et al., 2019), and qualitative results from experts, interviews and surveys (Liquete et al., 2016; Watkin et al., 2019). This diversity in outputs challenges the integration of different approaches. To counteract this, the following pre-assessment guidance aims at calculating a numerical value (in its actual unit) for each indicator. The numerical values can then be used for evaluation or further analysis (e.g., monetization, composite indicators).

Table 2: Summary of existing frameworks and tools related to co-benefit and disbenefit assessment (Type: M&E (Monitoring & Evaluation); M/A (Mapping/Assessment); Pre-A (Pre-assessment))

Source	Focus	Type	Air Quality	Carbon Storage	Soil Health	Water Quality	Temperature	Habitat Connectivity	Ecosystem	Biodiversity	Noise Attenuation	Energy Savings	Recreation	Tourism	Job Opportunities	Tax Revenue	Property Values	Health & Well-being	Social Cohesion
Co-benefits Assessment Framework (Raymond, Frantzeskaki, et al., 2017; Raymond, Pam, et al., 2017)	Climate Mitigation and Adaptation Water Management Coastal Resilience Green Space Management Air Quality Urban Regeneration Participatory Planning and Governance Social Justice and Cohesion Health & Well-being Economic Opps and Green Jobs	M&E		✓	✓		✓	✓		✓		✓	✓		✓		✓	✓	
Integrated valuation of NBS (Liquete et al., 2016)	Water Pollution	M&E		✓		✓				✓				✓					
Benefit of NBS Assessment Framework	DRR	M&E	✓	✓		✓	✓	✓		✓	✓		✓		✓		✓	✓	✓

(Watkin et al., 2019)																			
Environmental Impact Assessment of Projects (EIA) (Lantieri, Adrien; Lukacova, Zuzana; McGuinn, Jennifer; McNeill, 2017)	Climate Change DRR Biodiversity	Pre-A	✓		✓	✓	✓			✓			✓	✓				✓	
Evaluating the impact of Nature-based Solutions (European Commission, 2021)	Climate Resilience Water Management Natural Hazards Green Management Biodiversity Air Quality Place Regeneration Sustainable Urban Transformation Participatory Planning Social Justice & Cohesion Health & Well-being Economic Opps & Green Jobs	M&E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EU Ecosystem Assessment (Maes et al., 2013, 2020)	Ecosystem Services	M/A	✓		✓	✓	✓						✓	✓					
Recreational Opportunity Spectrum (Paracchini et al., 2014)	Ecosystem Services	M/A											✓						
Urban Ecosystem Service Assessment (Balzan et al., 2021)	Ecosystem Services	Pre-A	✓	✓			✓				✓		✓						
i-tree Tool (USDA Forest Service et al., 2006)	Climate Change Mitigation	Pre-A	✓	✓															
Benefit Estimation Tool (B£ST)	Flood Management	Pre-A	✓	✓		✓				✓	✓		✓	✓	✓			✓	

(Susdrain, 2019)																			
InVEST Tool (Natural Capital Project, 2018)	LULCC Ecosystem Services	Pre-A		✓		✓	✓						✓						

8.2.3 Quantification of co-benefits and disbenefits

The quantitative pre-assessment of co-benefits and disbenefits shall support the overall NBS selection and permission process. As introduced above, NBS are commonly selected based on a broad range of criteria. The pre-assessment of potential side effects shall further complement the evidence-based decision-making on suitable NBS. Before quantifying the side effects, co-benefit and disbenefit indicators need to be selected: co-benefits and disbenefits are greatly dependent on the NBS intervention and the local context, hence, prior to the quantification, a strategy is to narrow down the number of indicators. Potential indicators can be selected by using developed matrices (NWRM, 2015a; Raymond, Pam, et al., 2017; Wendling & Rinta-Hiiro, 2019) or by reviewing case studies from NBS databases such as the OPERANDUM NBS Catalogue (OPERANDUM, 2020). Selected indicators can be further aligned to the needs and interests of citizens and stakeholders who represent the main beneficiaries of an NBS. For instance, Giordano *et al.* (2020) and Liquete *et al.* (2016) incorporate stakeholders' and citizens' perceptions and needs by integrating weighted criteria considering the level of importance of each indicator to the community.

After narrowing down the list of indicators, the actual pre-assessment of co-benefits and disbenefits can be processed. The expected impact of each NBS can be calculated for every indicator based on methods introduced in Table 3. The methods introduced are largely acknowledging interlinkages between indicators. For instance, property prices are not only calculated based on the distance to green spaces but further incorporate improved air quality, reduced noise, and thermal comfort. In some cases, it might be more suitable to use proxies (e.g., nitrate and phosphor concentrations as proxies for water quality) which are introduced in Table 3. For the calculation of potential changes, a baseline approach (Lantieri, Adrien; Lukacova, Zuzana; McGuinn, Jennifer; McNeill, 2017; Maes et al., 2020) should be adopted. In

many cases, it might not be necessary to assess the baseline directly due to existing data repositories at European scale with representative and openly available baseline data. In this context, Table 3 suggests a baseline dataset for each indicator. Considering local contexts, these baseline maps may be partly too coarse as a baseline, but comparable datasets might be available at (sub-)national level. The quantified outcomes can then be evaluated (as discussed in Section 8.2.4) and integrated into the comparison of different alternatives. Also, Table 3 lists thresholds found for some indicators to support the evaluation of significance (see Section 8.2.4).

Table 3: Summary of quantification approaches for co-benefits and disbenefits indicators along with suggested baseline data, and thresholds

Indicator	Quantification/Reported Values	Threshold	Baseline Data
Air Quality Proxies: NO_2, PM10, SO_2, O_3	*Quantification:* changes in air quality can be estimated with the Pollutant Flux (Nowak et al., 2006; Tiwary et al., 2016) based on estimations of the leaf area index or directly with the i-tree tool (USDA Forest Service et al., 2006) *Reported values*: Horton *et al.* (Horton et al., 2019) summarised average pollutant uptake values for the above-mentioned proxies by trees and green roofs	Directive 2008/50/EC	Air Quality Statistic maps by the European Environment Agency
Carbon Storage & Sequestration by Vegetation	*Quantification:* sequestration by vegetation can be estimated with allometric equations based on dry weighted (above ground) biomass as applied by the i-tree tool (USDA Forest Service et al., 2006) *Reported values*: the Urban Nature Navigator (Naturvation, 2021) summarises carbon storage values per square meter for different urban NBS	Vegetation tolerance: air pollution tolerance index	Carbon sequestration (by forests) by the Joint Research Centre
Carbon Storage & Sequestration by Soil	*Quantification:* carbon stocks in soils are dependent on land cover and land use (IPCC, 2006; Natural Capital Project, 2018), climate regions and soil types (IPCC, 2006), and urban-rural areas (Pouyat et al., 2002). InVEST (Natural Capital Project, 2018) provides estimates for different land uses/covers	Topsoil organic carbon contents/ capacity depends on the soil	Soil organic stocks by the European Soil Database
Noise Attenuation	*Quantification:* the Noise Attenuation Potential by Tiwary *et al.* (Tiwary et al., 2016) can be used to estimate noise reduction with average leaf biomass and canopy area of trees and hedges *Reported values*: a buffer of 15-30 m width can attenuate about 6-10 dB while an avenue reduces about 4 dB (Dobson & Ryan, 2000; Kalansuriya et al., 2009). In comparison, a 3 m high wall can reduce road noise by 15 dB (Dobson & Ryan, 2000)	Directive 2002/49/EC	NOISE maps by the European Environment Agency
Water Quality Proxies: Nitrate,	*Quantification:* nutrient retention by vegetation can be estimated with the InVEST tool (Natural Capital Project, 2018)	Directive 76/160/EC	Waterbase Water Quality by the European

Phosphor, and Sediments	*Reported values*: e.g., nutrient load reduction by riparian buffer strips (Hawes & Smith, 2005)		Environment Agency
Soil Health Proxy: Bulk density	*Quantification:* bulk density can be used as a proxy for soil quality. Bulk density is dependent on the soil type but also the land cover. *Reported values:* e.g., Vandecasteele *et al.* (2018) reports on examples of bulk density changes due to LULCC	Bulk densities of 1.47-1.8 g/cm3 are restricting root growth	Topsoil physical properties data by the European Soil Data Centre
Temperature Regulation Proxy: Thermal Comfort	*Quantification:* universal thermal climate index (UTCI)	UTCI Index	UTCI (1981-2010) by Copernicus Climate Store
Habitat Quality Proxy: Habitat Connectivity/ Fragmentation	*Quantification:* green spaces can be implemented to connect habitats and therefore, increase their quality. Habitats are fragmented by built environments including roads (so called Fragmentation Geometry). The mesh density is a measure to determine the wildlife corridors and fragmentation	Minimum habitat sizes for animal species	Mesh density by the Joint Research Centre Ecosystem map by the European Environment Agency
Ecosystem disservice Proxy: Pollen	*Quantification:* can be calculated on local changes e.g., tree species	Daily mean concentration per m3 (Kurganskiy et al., 2020): low (1-10), moderate (10-100), high (100-1000), and very high (>1000)	European Aeroallergen Network
Ecosystem disservice Proxy: Mosquito	*Quantification:* can be estimated based on area of standing water or in extreme low flow river/stream sections. Different habitats and distribution areas need to be considered. *Reported values*: Sunahara *et al.* (2002) reported that mosquito larvae in habitats smaller than 0.1 m2 have a better chance to survive (in regard to predators) as in water areas greater than 0.1 m2. Mosquito breeding is also dependent on habitat connectedness and water temperature.	Nuisance Thresholds	European Centre for Disease Prevention and Control
Recreation	*Quantification:* according to Lee *et al.* (Lee et al., 2015) and Schägner *et al.* (2016), the attractiveness of a space for recreational purpose is depending on the size of the area, the proximity to population, the accessibility in terms of transportation but also the quality and aesthetic of the space. This indicator shall estimate visitor numbers of green or blue	A few sources (i.e., Abdullah *et al.* (2016) or Niemelä *et al.* (2010)) report on minimum	Recreational Opportunity Spectrum by the Joint Research Centre

	spaces which can be further linked to health and well-being but also socio-economic development. Usage can be estimated in different ways, for instance, the travel cost method or with the Recreational Opportunity Spectrum (Paracchini et al., 2014)	sizes of recreational spaces for different activities and the maximum distance to the space	LUISA base map by the Joint Research Centre
Tourism	*Quantification:* the Recreational Opportunity Spectrum concept can be used to assess the NBS area based on its naturalness, proximity, and other factors (e.g., species richness) (Paracchini et al., 2014)	*No threshold was found but a limitation could be the maximum number of people per km2 to preserve the naturalness of the place*	Recreational Opportunity Spectrum by the Joint Research Centre
Job Creation	*Quantification:* the number of employees in green space maintenance can function as a proxy for job creation. However, this co-benefit also includes job and/or business creation for the implementation of an NBS. Estimations could be based on average monthly/annual maintenance hours per unit of green space or from reported impact in NBS case studies	*No threshold found*	Unemployment data by Eurostat or local data or from local datasets
Property Values	*Quantification:* air quality, noise levels, thermal comfort, and the proximity to green/blue spaces are influencing property prices which can be calculated with the hedonic pricing method	Unaffordable housing costs can function as a threshold which lies around 40 % of the disposal income within Europe (Eurostat, 2021)	Property Values: local datasets from e.g., housing agencies. Income by households: by Eurostat or local data
Tax revenue Proxy: property/real estate transfer tax (or tourism, tax income from increased number of jobs)	*Quantification:* tax revenue benefits from increased property values. Increased tax revenue can be calculated based on e.g., transfer taxes *Reported values*: Property/Real Estate Transfer Tax for Europe can be found in Barrios *et al*. (2019)	*No threshold found*	*No baseline data found*

Social Cohesion/ Inclusion	*Quantification:* social inclusion can be enhanced by green spaces promoting social contacts and the feeling of inclusion. While the co-creation of NBS can increase social cohesion and feeling of ownership of the place. Equal access to green space can be estimated by assessing households in proximity and the diversity of incomes. Other estimates of the cohesion and the feeling of ownership of the place can be made based on the potential of co-creation of the NBS. The type of green/blue space can imply the potential interactions (e.g., playgrounds may offer more possibilities to interact with others than a wetland)	*Threshold for exclusion - see property values*	Local household income data is needed
Energy savings	*Quantification:* InVEST (Natural Capital Project, 2018) suggests an energy saving equation comparing baseline temperature and estimated temperature reduction *Reported values*: Santamouris *et al.* (2015) provides global energy cost examples for 1 K increase in temperature	Energy Performance of Buildings Directive (EPBD)	Energy prices and consumption statistics by Eurostat or local datasets
Biodiversity Proxy: Birds	*Quantification:* biodiversity is influenced by soil health, habitat connectivity, water quality, and ecosystem disservices. Many proxies are identified for biodiversity like species richness of specific taxa or the number of distinct plant functional types, but they must be integrated with other metrics to fully capture biodiversity. EASAC (European Academies Science Advisory Council (EASAC), 2005) defined a set of biodiversity indicators including population trends, land use change, threatened species, coverage of protected areas, and trends in abundance and distribution of selected species. For urban environments, the city biodiversity index is another option (Chan et al., 2014).	Species (Plant and Animal) Thresholds	Bird Atlas by European Bird Census Council (EBCC)
Health & Well-being	*Quantification:* this indicator is determined considering several aspects: increased recreational areas, reduced heat stress (e.g., quantifiable with the Universal Thermal Climate Index), air quality improvement, noise attenuation, ecosystem disservices but also by enhanced social cohesion and inclusion or the created jobs and income from tourism. Literature has been focusing on monetizing this indicator, for instance, by estimating avoided costs in the health sector or with the willingness to pay method. Health thresholds: see air quality, noise attenuation, thermal comfort		

8.2.4 Evaluation

The resulting numerical values calculated for each indicator need to be evaluated to fully understand the expected extent of co-benefits and disbenefits – i.e. how significant is the change and whether the change is positive or negative, or how sustainable is it considering long-term effects and contribution to SDGs and other global environmental frameworks. In this section, we discuss the three research

questions by drawing on existing frameworks and data manipulation methods to answer them.

1) How significant is the actual impact?

Significance plays a major role in the context of the EIA Directive where projects with significant impact on the environment need to undergo this process. However, it does not define a threshold for significance – i.e. which rate of change counts as significant? As part of the ecosystem assessment framework, Maes *et al.* (2020) approached the analysis of significant change statistically by calculating decadal trends and defining a '5% per decade rule' - meaning that changes from +/-5% within a decade are of significance.

To be able to assess the significance of change, the quantification should encompass a first assessment of the pre-NBS situation of the area (baseline) for each of the selected indicators (Lantieri, Adrien; Lukacova, Zuzana; McGuinn, Jennifer; McNeill, 2017; Maes et al., 2020). A great amount of baseline data is available at European scale as introduced in Table 3. Additional baseline data can be obtained from e.g., remote sensing, numerical modelling, social media analysis, or crowdsourcing. Despite the large amount of available data worldwide, they can be lacking sufficient quality in terms of accuracy, metadata, or appropriateness. In case that no sufficient data are available, a baseline can be assessed e.g., according to Maes *et al.* (2020). The results of the pre-assessment of co-benefits and disbenefits can then be compared to the baseline and the rate of change can be calculated.

Furthermore, co-benefit and disbenefit values can be evaluated regarding certain thresholds (enlisted in Table 3). In particular, it can be evaluated whether they are meeting the local needs by setting the resulting value into local context. This will further help to understand the significance of change. As an example, if the noise pollution level is 69 dB due to traffic, introducing treelines along the road shall diminish the traffic noise. Grown trees may then be able to reduce the noise by 9 dB which would be a reduction of 13% which is not sufficient to reduce the noise to an acceptable (EU threshold) level of 53 dB.

2) When can co-benefits turn into disbenefits?

Co-benefits may evoke certain disbenefits such as social exclusion due to raising property prices while in some cases co-benefits can turn into a disbenefit. As

exemplified in the introduction, high leaf density of a hedge or avenue can function as a barrier for air pollutants causing high levels on one side and low levels on the other side (Abhijith et al., 2017; Barwise & Kumar, 2020).

In Watkin *et al.* (2019), the rate of change is calculated in percentage and translated into a score ranging from 0 to +/-5 (low to high) while 0 indicates no change. This approach further allows negative scores that can unveil when a co-benefit may turn into a disbenefit. Applying the statistical method by Maes *et al*. (2020), the percentage of change can also indicate whether the change is positive or negative. For instance, in the above example, a negative change of air pollution would indicate a 'good' change while a positive rate of change would indicate an increase in pollution.

3) How sustainable is the NBS in the area of interest?

Considering the range of co-benefits and disbenefits, it is obvious that they are covering the three pillars of sustainability (economy, society, and environment). For a specific analysis about how co-benefits cover and support them, a composite indicator can be calculated (*Handbook on Constructing Composite Indicators: Methodology and User Guide*, 2008). Furthermore, quantified outcomes of the indicators can be discussed in context with global frameworks such as the SDGs or the targets of the CBD, but also local/municipal goals. This will establish an understanding of how the NBS simultaneously address other challenges and goals.

Sustainability also refers to addressing the needs of the future. In order to evaluate how an NBS will perform in the future considering changing climate, Calliari *et al.* (2019) proposes a framework for backcasting NBS to pre-assess direct and indirect benefits linked with costs and to evaluate the suitability of NBS in projected future climate conditions.

Schaubroek (2017) questions whether NBS are sustainable referring to the temporal aspect of their impact. In this context, it needs to be understood how the impact is to be expected in time (but also in space). Raymond *et al.* (2017) highlights the issue of uncertainty of the effect in time due to local changes or changes in climate but considering the impact in time and space is non-neglectable. In accordance with the above example, reaching a 9 dB reduction is highly dependent on the tree height, canopy density, and the season – in the view of existing differences between evergreen and deciduous trees. For some indicators, a difference in effectiveness may even be detectable between day and night. Nonetheless, the time scale over which an NBS

becomes effective depends primarily on the growth time of vegetation. Overall, it should be considered whether the NBS has short- or long-term impacts (Kabisch et al., 2016).

Also, co-benefits and disbenefits can have different spatial effects which are further dependent on local characteristics e.g., rural and urban growth differences but also on the size of the intervention, and on the indicator characteristics itself. Taking into account the vegetation growth time, impact may vary between urban and rural areas due to restrictions in vegetation growth (Nowak & Crane, 2002; Pataki et al., 2011; Raymond, Pam, et al., 2017).

8.2.5 Conclusion

This paper highlighted the need for quantifing co-benefits and disbenefits for NBS selection and permission processes. We reviewed available co-benefit assessment frameworks as well as tools and guidance from other disciplines such as the ecosystem service assessment. Available frameworks were found to be focusing primarily on monitoring and post-project evaluation of co-benefits by largely neglecting potential disbenefits. Whereas a number of tools were suggesting methods for pre-assessing co-benefits. Building on the existing research, this paper provides pre-assessment guidance to support decision-making on NBS for DRR by quantifying potential impact and evaluating its significance. The guidance was designed to assist in decision-making on suitable NBS and for the preparation of an EIA for NBS projects. The variety of quantification methods for indicators discussed in this paper underlines the need for an integrative model or tool by incorporating the existing interrelationships. As regards specific categories, the prediction of biophysical indicators as well as the availability of baseline data with sufficient quality and suitable resolution is at an advanced stage. Whereas this does not account for most of the socio-economic indicators. To overcome this lack of data, more research is needed for estimating socio-economic indicators i.e., based on new data sources such as social media. An additional challenge is the resolution of baseline data at European scale as fine resolutions are associated with large files. Fine resolution datasets likely exist at municipal level but are often not openly available. Another key point of this paper was the investigation of potential disbenefits and the need to include them into

the assessment process. Additional studies are needed to unveil disbenefits to fully integrate them into decision-making and impact assessment.

Nature-based Solutions are of increasing importance around the world due to their co-benefits for the environment, society, and economy. While NBS are addressing Disaster Risk Reduction, co-benefits are rather supporting the SDGs, targets of the Paris Agreement and the CBD. This trend of NBS is a significant step towards the aforementioned global frameworks. However, to fully grasp the contribution of NBS to these frameworks, it is necessary to quantify the co-benefits and the disbenefits. Only with the quantification of those it is possible to make evidence-based statements on the impact of NBS on those frameworks.

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Who did what? Joy Ommer 85% (conceptualisation, investigation, visualisation, writing, review & editing); Edoardo Bucchignani (conceptualisation, investigation, review & editing); Laura S. Leo (Supervision); Milan Kalas (supervision, review & editing); Sasa Vranic (technological implementation, review & editing); Sisay Debele (supervision, review & editing); Prashant Kumar (supervision, review & editing); Hannah L. Cloke (conceptualisation, supervision, review & editing); Silvana Di Sabatino (Supervision)

9 Facilitating the uptake of no-regrets actions

Until this point, this thesis has broadened the risk perception scholarship, compared the perceived and legal-institutional risk management structures, and introduced regret as a decision-making variable into disaster science. In addition, two practical frameworks were introduced to support preparedness action communication and NBS preassessments. However, until this point, this thesis stayed at a theoretical level; thus, now, it is situated at the edge of a theory and practice gap. Chapter 10 will discuss the uptake of the theoretical insights by the research community, but this chapter 9 will explore 1) the existing gap between theory and practice (Section 9.1), and 2) ways to bridge the knowledge-action gap by making scientific knowledge accessible (Section 9.2) and facilitating the practical application of it (Section 9.3 and 9.4). In this regard, this chapter aims to *identify methods and tools to facilitate the uptake of no-regrets actions for disaster preparedness by citizens in practice (Objective III)*.

Bridging theory and practice. The move from theory to practice often appears to be easier written on paper than in reality. An example are flood action groups. Throughout this thesis, we have seen that flood action groups can be valuable for bridging the interface between local authorities by i.e., co-defining risk governance responsibilities, or co-creating solutions for risk reduction. In addition, it was discussed in Chapter 5 that interactions between flood action groups and local authorities shall be multi-directional. In Chapter 7, flood action groups were listed as one no-regret solution for increasing flood preparedness. In fact, it was also discussed that collective action can be a motivational factor to prepare for future hazards. In practice, flood action groups in Germany seem to be far away from theoretical ideologies. Demonstrating this existing gap between theory and practice, Section 9.1 includes insights on the reality of flood action groups striving for local preparedness.

Making scientific knowledge accessible to citizens. Scientific knowledge is not always accessible to citizens (Gonzalez-Ollauri et al., 2023). Meaning that scientific resources are not available or understandable to lay people. For instance, within a project, I have been working with a community which realised that their village in

Scotland is at risk of coastal erosion as the cliff in front of their homes is slowly moving. Realising this threat, neighbours grouped up to identify ways to prevent this erosion but since none of them was an expert in this field they were unsure where to start. Finally, the community contacted the nearest university asking for support.

Making scientific knowledge accessible does not mean that citizens and communities shall decide on, implement, and manage risk reduction measures all by themselves, but rather offering them a starting point and the opportunity to increase their knowledge on e.g., different options, risks, etc. For instance, providing information and guidance on different possible Nature-based Solutions. Hence, citizens can learn about potentially suitable solutions, their requirements, and eventually finding a cost estimation or experts for these solutions. Making this scientific (and practice) knowledge accessible can empower and activate citizens. Section 9.2 discusses a decision-support toolkit for Nature-based Solutions which aims to make scientific knowledge accessible to citizens to enhance their community preparedness.

Facilitating practical application. It was argued that top-down awareness campaigns are not always effective as citizens are situated at the end of the chain as passive receivers (Heidenreich et al., 2020; Nikkanen et al., 2023; UNDRR, 2022). Throughout the past decades, various theories and methods were developed that aim to bridge the gap between knowledge and actions. For instance, participatory methods encouraging citizens to participate in local actions, share their knowledge and opinions while, at the same time, perhaps increasing their awareness, knowledge, and action taking (Anderson et al., 2022; Chambers, 1983; van Manen et al., 2015). Hence, shifting from knowledge receivers to creators (Mees et al., 2018; Nikkanen et al., 2023). Recent advances are focusing further on the motivational aspects e.g., by integrating game elements (Wee & Choong, 2019). Yet, a facilitator may be non-neglectable. In particular, a facilitator aims to support these processes of shifting towards knowledge creators, motivating towards take action, etc. In this sense, a facilitator can take many forms such as a flood action group, teacher, local authority, or simply an app. In support of the third and final objective of this thesis, two facilitation tools will be presented that aim to bridge the knowledge-action gap: a gamified application facilitating behavioural change towards no-regrets (Section 9.3) and a serious game

encouraging citizens to become knowledge and solution creators for their local climate change mitigation and adaptation (Section 9.4).

9.1 Flood action groups – a no-regrets action but also facilitator?

The value of flood action groups for promoting and facilitating local preparedness was indicated throughout this thesis (Chapter 2,5,7). However, the reality of flood action groups and their potential for facilitating preparedness behaviour is not always as easy as it may come across literature. This section looks at the reality of flood action groups in Germany and discusses aspects to facilitate collective action through initiatives like them.

9.1.1 Introduction

The experiences of the flooding event in Germany in 2021 motivated many citizens to group into flood action initiatives. Firstly, Facebook groups emerged with the ambition to allocate help for the response to the flooding and for the recovery. These social media groups were very effective for collecting responses to the survey conducted within this thesis. Secondly, formal initiatives and associations were founded in the aftermath of the event with the ambition to evoke a change in local flood risk governance and management to lower the impact of future flooding. In order to learn more about the activities, achievements, and challenges of flood action groups, a forum meeting was organised for them to build a space for exchanging their experiences across different regions.

9.1.2 Methods

The forum meeting was organised as part of the 'Woche der Klimaanpassung 2023'. This national week on climate change adaptation invited municipalities, regions, universities, and other organisations and institutions to organise workshops, discussions, walks, and more. These events were all promoted via one platform organised by the federal government. As part of this week, I organised two forum meetings in form of focus group discussions. The first meeting was targeting the experiences of flood action groups and was held on 19th September 2023. The second meeting was focusing on individual preparedness for flooding and took place on 21st September 2023. In both meetings, three flood action groups participated with one to

three members per group. The groups were from different areas across Germany: district Rhein-Erft-Kreis (North Rhine-Westphalia), City of Cologne (North Rhine-Westphalia), and district Haßberge (Bavaria). Each of the groups experienced different types of flooding: a small stream exceeding its banks, a retention pond exceeding its capacity, and pluvial flooding, respectively.

Ethical approval. The focus group discussions were approved by the SAGES Ethical Committee of the University of Reading (Amendment SAGES-REC-2022/24 on 19th June 2023).

9.1.3 Flood action groups – a facilitator for local preparedness?

The literature review (Chapter 2) and the empirical study (Chapter 5) have highlighted the value of and need for flood action groups for increasing social and individual self-responsibility, mediating the interface between citizens and authorities, and overall, enhancing local disaster preparedness. In the following, these aspects are discussed with the insights shared by flood action groups within the workshop.

How to start? Flood action groups were founded through self-organisation of citizens in the aftermath of the event. Each of the groups aim at raising their voice to make an impact on lacking local flood risk management. The groups were initiated by a few friends and/or neighbours who were directly affected by flooding. This is an example of when flooding experiences can function as a motivation to take responsibility and (try to) initiate a change as a collective (Platt et al., 2020). Some of these groups stayed as an initiative while one became a formally acknowledged community of interest which involves an official contract and offers the possibility to receive funding. The groups highlighted the challenge of motivating other citizens to participate in events or to join the group which was partly reasoned by the initiatives with the fact that citizens are not interested as there is no imminent risk anymore which is often observed (de Guttry & Ratter, 2022; Forrest et al., 2019). This indicates that the value of collective behaviour is not always enough to motivate other citizens.

Where to start? In their initial stage, two groups focused on gaining an insight into risk areas, developing potential flood risk reduction recommendations (i.e., buying mobile

flood protection walls for the municipality), and sending these to the municipality. The groups were highlighting that it was partly difficult to know which solutions would be suitable because they are not experts in this field. This suggests that there is a need to make expert and/or scientific knowledge of potential solutions available, accessible, and understandable to citizens (which will be discussed in Section 9.2). The third group rather focused on unfolding the flooding event, why did the retention pond spill over, why was the inflow not stopped, etc. Based on their findings, the management of the retention pond failed, and they presented this conclusion to the municipality.

Multi-directional interactions. In all cases, the communication between the flood action groups and local authorities was one-directional (bottom-up). They reflected that it was very difficult to receive answers to their questions and reactions to their flood risk reduction suggestions. Only when starting to approach specific people e.g., from the hydrological department or representatives of different political parties, they managed to be heard, but it was far from multi-directional interaction. A first step may be to emphasise the values of multi-directional interaction (Mees et al., 2018), and provide resources and guidance to municipalities on how to build close relationships.

Collective governance. The main difficulty all groups were facing is that they feel not acknowledged and their opinions not heard nor valued by the municipalities within the first years and some even nowadays. For flood action groups to function as a bridge, they need to be at least informally acknowledged by municipalities and engaged in decisions and actions (Emerson et al., 2012). In this context it was highlighted that the first step towards this direction needs to be taken by the municipalities e.g., by initiating dialogues (Forrest et al., 2021). Perhaps, the municipalities, especially, small ones, do not have the resources, knowledge, or capabilities to connect with these citizen groups and to let them grow into their full potential.

Joint responsibilities. Strong relationships and especially trust, can support flood action groups taking on more responsibilities or creating joint responsibilities (Felletti & Paglieri, 2019; Mees et al., 2018; UNDRR, 2022). The groups have been actively promoting their initiative. For instance, one group has organised workshops together with the municipality and other organisations to map flood impacts and flood

mitigation strategies. They mentioned that they would eventually take up more responsibilities, but they were very careful and did not take any responsibilities for which they are not 'experts' of. For instance, they would not feel comfortable in educational activities as they are not experts in disaster risk management, but they mentioned that they could support experts. In addition, they are happy to raise awareness on topics they do not need any technical knowledge. Their willingness to take on more responsibilities could perhaps be encouraged through closer collaboration with authorities and experts, and hence, could also strengthen their knowledge and capacities over time.

No-regrets actions. One group mentioned that they were cleaning the bed of the stream with local citizens after the flooding. They mentioned that this was not well received as there might be legislative restrictions. Overall, it is perceived that some Nature-based Solutions might be suitable, but they would need to go through an official approval process. After about two years, none of these groups has achieved that their disaster risk reduction suggestions went any further then when they submitted them.

9.1.4 Ways forward

Overall, it was highlighted that this exchange between different action groups was very helpful to exchange challenges, frustrations, but also to advise each other on potential solutions. Therefore, it can be recommended to support this exchange between different municipalities or regions.

In regard to the third objective, this section underlined the potential value of citizen initiatives for facilitating local disaster preparedness. However, the main barriers are the lacking initiative for collaboration by local authorities and the motivation of other citizens (i.e., through flood experience and the realisation of the lacking flood risk management by local authorities). Therefore, it may be concluded that citizen initiatives could be a facilitator for local preparedness if authorities acknowledge them as a valuable element of local flood risk governance. Yet, the groups cannot always overcome existing barriers of citizens preparedness motivation by themselves.

9.2 The NBS Toolkit – a decision-support

Awareness and knowledge about risk and potential actions or solutions is the key for disaster preparedness. In this context, the previous section noted that citizen groups had difficulties in identifying suitable solutions for local flood risk reduction because they are not experts in this field. This underlines the need for making scientific knowledge more accessible and understandable for citizens to empower them to create ideas and take actions. In response to this need, this section introduces the NBS Toolkit[4] which exemplifies a science-based tool aimed at facilitating citizens in knowledge gathering on potential Nature-based Solutions for their area.

9.2.1 Introduction

Imagine, you were recently affected by a devastating flood. Now, you are grouping up with your neighbours. Together you are discussing possible actions to be better prepared in the future, but mainly you are thinking about solutions for reducing the disaster risk in your area. As you are all not geographers or similar, you are unsure about which solutions could be possible. To support your idea collection stage, the NBS Toolkit (Figure 11) was developed for Europe which recommends Nature-based Solutions based on your (selected) area and the hazard you aim to minimise. These recommendations are the outputs of a suitability mapping process combining hazard exposure, land cover, soil, and topography. In a next step, you can browse the recommendations, compare them with another, test them in a future climate, and receive guidance for their implementation.

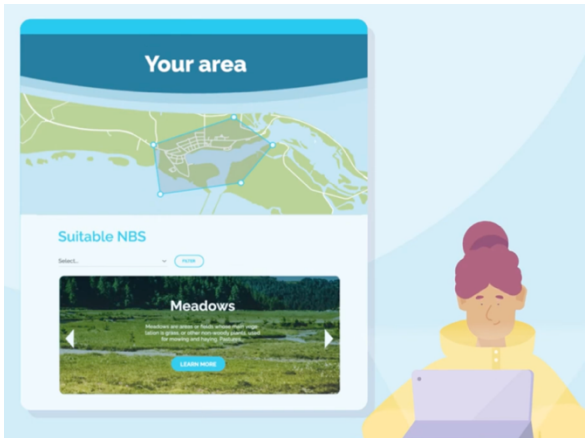

Figure 11: The Nature-based Solution Toolkit

9.2.2 Method

Nature-based Solutions are not suitable everywhere as they have spatial requirements; thus, for decision-making on potential NBS for an area, multiple criteria need to be assessed and fulfilled. For this type of multi-criteria assessment, the NBS

[4] https://geoikp.operandum-project.eu/nbs/toolkit

Toolkit builds on the method of suitability mapping (Mubeen et al., 2021; Sarabi et al., 2022). Considering that there are many criteria that can influence the decision-making on Nature-based Solutions, the suitability mapping of this toolkit includes the criteria which are given (and not related to individual preferences) such their potential to reduce the likelihood of a hazard or multiple hazards (Liquete et al., 2016; Raymond, Frantzeskaki, et al., 2017) with respect to future climates (Calliari et al., 2019; Cohen-Shacham et al., 2019; Emilsson & Ode Sang, 2017), based on a set of NBS requirements (Bach et al., 2013; Ellis & Viavattene, 2014; Guerrero et al., 2018; Kuller et al., 2019; Mubeen et al., 2021). These NBS requirements are related to i.e., flood exposure, land use and land cover, forest density, soil, built-up areas, and water areas. After selecting and setting the criteria for each NBS based on literature reviews, the suitability mapping will output spaces where a specific NBS could be potentially implemented.

Note: The full suitability mapping process (including data selection, GIS processing steps, and validation) is described in Appendix 4.

9.2.3 Further decision-making

The NBS recommendations are presented with information on criteria used for the suitability mapping and on criteria which were identified as important for decision-making on NBS such as (co-)benefits and costs (Cohen-Shacham et al., 2019; Liquete et al., 2016; Ommer et al., 2022; Raymond, Pam, et al., 2017). Yet, this may not be all information needed but everything the toolkit can inform about. To not just leave the users alone after going through the process of the toolkit, the toolkit provides guidance on next steps towards the co-implementation of NBS. This guidance informs about potential additional factors that may need to be taken into account i.e., social factors (e.g., acceptance of the NBS by the general public and authorities), legal factors (e.g., land ownership, policies in context of the permission of NBS), and economic factors (e.g., funding for the land reimbursement, implementation, and maintenance) (Amirzada et al., 2023; Anderson & Renaud, 2021; Croeser et al., 2021; Giordano et al., 2020; Kuller et al., 2019; Mubeen et al., 2021).

Lastly, it needs to be mentioned that this tool is designed for the pre-selection of NBS, and the next step would be to perform a real assessment on the suitability of these pre-selected NBSs.

9.2.4 Conclusion

Some no-regrets actions may not need much guidance to implement them, but Nature-based Solutions do because of the variety of criteria that need to be considered. In order to assist citizens and initiatives in learning about different solutions, the NBS Toolkit is an example for bridging scientific knowledge to non-experts and therefore, supports the third objective of this thesis.

Acknowledgements. This work was supported by the European Union's (EU) Horizon2020 research and innovation program. It was funded by and carried out within the framework of the OPERANDUM (OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteorisks) project (Grant No. 776848).

Who did what? The NBS Toolkit framework was conceptualised by me and with the help of Milan Kalas. The content was developed by me with the help of the project's living labs who provided information on the NBS they have been working on. The method was developed by me using GIS which was then transformed into a python environment by my colleague Saša Vranić who also developed the backend and front end of the toolkit together with other colleagues. The user interface was designed by a subcontracted company.

9.3 ChallengeYeti – The no-regrets app for climate change mitigation

The previous section presented the NBS Toolkit as an example for bridging scientific knowledge to citizens and providing guidance, but the toolkit does not directly focus on bridging the knowledge-action gap. Since other no-regrets actions (besides Nature-based Solutions) may require or foster a change in behaviour of citizens, this section is presenting an application for facilitating a behaviour change with no-regrets actions.

9.3.1 Introduction

Hello, I'm Yeti! As we know, Yeti is primarily known for its huge footprint, and no-one knows where this footprint comes from – but perhaps it was a Yeti (Figure 12). The app ChallengeYeti[5] was designed to tell a different story about

Figure 12: Yeti of ChallengeYeti

[5] https://challengeyeti.com/

our individual footprint. The world wide web is hosting an overload of carbon footprint calculators which aim to estimate our individual footprint from different sectors such as energy, transport, or consumption. After having evaluated your footprint, you are left alone with a number that presents carbon in kg. In some cases, websites offer carbon offsetting options or provide some indications of how we could reduce our footprint. But how does this awareness on our footprint make us change our behaviour? Perhaps, we are more attentive to certain things such as eating a steak, but we might still eat it. So, how can Yeti make us change our behaviour?

9.3.2 Approach

Building on the concept of the COM-B model (Michie et al., 2011), behaviour change can be triggered with three simple ingredients: 1) Capabilities that enable us to accomplish something; 2) an Opportunity to make the change; and most importantly; 3) Motivation to do something.

Capability. Psychological and physical capabilities are needed to take an action. These may refer to our knowledge or certain skills (Michie et al., 2011). To enable more people to take actions these shall not require an immense set of capabilities and effort too far from our comfort zone. No-regrets actions were selected because they shall be easy-to-implement (according to the framework developed in Chapter 7). In this app, the no-regrets framework is adopted for climate change mitigation actions. These actions are flexible in time or frequency at which they are performed. In other words, users can define themselves whether they cycle to work once, one week, or they simply track every time they do so (instead of using the car). This way, actions can be tailored by the users to their own capabilities. Moreover, the app works in a step-by-step way; thus, users are not asked to change their entire behaviour in one day, but rather can take actions in their own pace, and hence, the longer-term usage of the app could help increasing capabilities step by step.

Opportunity. Having the capabilities, an opportunity is needed where these can be applied (Michie et al., 2011). Here, the app itself is offering an opportunistic space to browse and take actions. Yet, for taking an action, motivation is necessary as a final ingredient.

Motivation. This ingredient is probably the most important one because without motivation it is difficult to start taking action but also difficult to continue (Wee & Choong, 2019). Motivation can be either intrinsic or extrinsic and is influenced by our capabilities and opportunities, and vice versa (Michie et al., 2011; L. S. Morris et al., 2022). Intrinsic motivation describes the psychological force that motivates us because we find something interesting or enjoyable. Extrinsic motivation works with external influences such as rewards or money which motivate us to do something. ChallengeYeti aims to trigger our intrinsic and extrinsic motivation primarily through gamification by integrating the following game design elements (Wee & Choong, 2019):

- *Reward*. The app builds on the idea not to calculate the actual footprint but to sum up the avoided footprint. For instance, when I actively decide to take the bike instead of the car (which I usually use), then this avoided footprint from not using the car will be noted and summed up over time. After reaching certain thresholds, the user receives a badge, for instance, a plane which means that as much CO2 was saved as one flight would emit.
- *Challenges*. One of the most common game design elements is the challenge. In this app, users can challenge themselves or others such as the parents. For instance, you can challenge your father to eat vegetarian food for one week. The element of challenging but also the social and intergenerational aspect can be important motivational factors to keep users taking actions.
- *Competition*. The app offers the possibility to create communities in which the community members can either take challenges together or they can compete with another. The latter one is fostered through a community leader which is based on the individual's avoided footprint.
- *Social network*. Communities are not only designed to compete but also offer a space for social interaction through a chat. This chat can be used to share possible actions or similar.

In addition, the app aims to encourage the users to think about additional no-regrets actions which they can add to the catalogue or simply use for themselves. This crowdsourcing approach supports the gathering of more actions but foremost shall motivate the users by turning them into knowledge (action) creators which reflects the idea of participatory approaches.

By date, the app is at a prototype stage and therefore, feedback was not gathered, and app data was not generated yet. For this reason, it is currently not possible to provide any insights on how the app promotes behavioural change, but it will be emphasised in the future.

9.3.3 Towards a no-regrets app for disaster preparedness

As we have seen, no-regrets actions do not require a high set of skills and knowledge, but people certainly need to be motivated to take actions, especially, if there is no imminent hazard or they have not experienced flooding or other hazards yet. The approach of ChallengeYeti can be tailored to disaster preparedness or climate change adaptation, in general. This may include using the reward system with levels, challenges, and the social network. Using a gamification approach could support the educational aspect as well as triggering actions. Therefore, our future ambition is to develop Yeti in a changing climate.

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Who did what? The app was designed and created within the I-CHANGE project by KAJO. The idea, conceptualisation, and content of the app were created and developed by my colleague Milan Kalas and me. The designs were outsourced to subcontracted company. The development of the app itself was performed by my colleagues from the IT department. With support from a project partner (Techne Consulting), carbon formulas were developed.

9.4 Our Climate Story – A serious game on climate change mitigation and adaptation

A second practical example for bridging the knowledge-action gap is the serious game presented in this section. The serious game incorporates the idea of turning citizens into knowledge creators or sharers – meaning that the game empowers the players to define which hazards can occur, where are the risk zones, and which solutions could be suitable.

9.4.1 Introduction

Write your own local climate story! Almost every day news is reporting about our greenhouse gas emissions accelerating the changes in our climate which in turn can result in more extreme hazards. What is your local climate like? Which hazards are common or could be happening in the future? How can we mitigate these hazards? This serious boardgame lets you explore your hometown from a different angle. As we have learnt earlier, serious games are increasingly used for awareness raising, education, and to promote behavioural changes. Our Climate Story aims all of these ambitions by taking a participatory approach for enhancing active and social learning.

9.4.2 The game and it's approach

Our Climate Story sets you into your own shoes. You and your community will be discussing your local climate and related risks, how to mitigate them, how to prepare for them, and how your daily choices might impact how the future climate will be. All these insights will be written down in your Own Climate Story book!

Figure 13: Our Climate Story book

The Our Climate Story book (don't worry – it is not as long as this thesis) will guide you through the whole game. Since it can be very boring or difficult to read many pages and gain some learnings out of it, this book does not dictate you everything you should know but it rather makes you and your playmates co-authors of it.

The book (Figure 13, Appendix 5) includes two phases, firstly, taking a snapshot of the current climate risks and possible solutions to reduce these risks and, secondly, you play your daily life.

Phase I. Before you can start, you actually need to define which area do you talk about in Our Climate Story. In this part of the game, you create your own playfield by drawing rivers, roads, forests, important places for you, and much more. In the second step, you are storylining (Shepherd et al., 2018) your local hazards. What does this mean? The aim is to unfold past hazard events and think about the future. Which hazards have occurred or may will. What is causing them primarily, what is at risk, and how can we

reduce the risk or protect us from the hazards in case they may happen. In this participatory exercise, you and your playmates gain the power to share your local knowledge with each other, discuss the local needs, and brainstorm and design your own future (Chambers, 1983; Klonner et al., 2021; Renn, 2015; Sullivan-Wiley et al., 2019; van Manen et al., 2015).

Phase II. Let's play! In the end, this is still a serious game and not a gamified workshop (Wee & Choong, 2019). It's a normal day in your life and all players have to do their daily things – go out of the house in the morning, maybe go to work, shopping, hiking, or similar and then back home. As we are all having a busy life, you of course want to do everything fast and be the first one reaching your home again. But how do you move? Do you walk which might be a relaxing exercise, you take the full tram, or just quickly the car? This phase of the game plays with our behaviours and habits which often lead to emissions. The main focus here lies on promoting active travel modes (Cook et al., 2022). For instance, when using the car, your emissions will be placed on the climate scale which encompasses the three emission scenarios (IPCC, 2014) and the worse the scenario, the more hazards can occur. These hazards are functioning as a disruption game mechanism because you may not be able to move for one round or certain risk areas are inaccessible. At first glance, this Phase II is competitive, but you can also collaborate with other players in climate actions; thus, it gains a collaborative-competitive character (Buchinger & da Silva Hounsell, 2018). The game includes a community fund which can be used to integrate mitigation or protection measures. But the whole community (all players) need to agree on the (mainly no-regrets) measure to be implemented. This element of the game is mirroring the difficulties of taking decision under uncertainty. From the climate scale, you can see that a hazard might be happening, but you do not know which hazard it will be. There are different ways how this game mechanism may be used. Firstly, you and the other players might actually forget to implement any solutions until a hazard strikes which then motivates the group to consider different solutions (Nicklin et al., 2019). Secondly, you may be proactively minded and discuss which solutions could be appropriate. In this case, you may suggest a solution for a hazard of a risk area which you may have to cross on your way. This can cause either agreements or large

disagreements between the players, but a decision needs to be made – take action or not.

9.4.3 Next steps

A first test round was performed within the General Assembly of the I-CHANGE project[6] in February 2024. In this test round, each pilot site designed the game board for their city as well as the hazards and possible solutions. The overall feedback was very positive, and suggestions made were integrated into the book. This session highlighted the difference between areas in terms of hazards, solutions, but also their approach. As this serious game is part of the project, the game will be played in different occasions of the project, especially, within events of the pilot sites. These occasions will be used to test the game thoroughly. A final version should be ready by September 2024. The game will be freely downloadable from the Citizen4Climate website[7]. Acknowledging that playing Phase I and II is very time consuming, we are developing game boards for each pilot site of the project based on the first test round. This way, the pilot sites can decide whether they let stakeholder play the full version (Phase I and II) or only Phase II with the pre-made game board.

In the future, different extensions could be made for this game. Firstly, a health extension which incorporates the different health impacts cause by the striking hazards. Secondly, one extension could discuss how climate is projected to change in the future and how this will affect the hazards frequency, magnitude, etc. Thirdly, one version may look at the cascading hazards and risks of one hazard. Lastly, the existing version(s) can be extended with virtual reality features showing how the flood would look like in a certain spot on the map. This last version can further help to foster imagination of hazards(Ommer, Neumann, et al., 2024).

Acknowledgements. This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101037193.

[6] https://ichange-project.eu
[7] https://citizens4climate.com

Who did what? The serious game was conceptualised in a team of three different project partners (KAJO s.r.o., Climate Media Factory, National Research Council of Italy (CNR). This team and the task itself are led by me. We had a conceptualisation meeting where we came up with the main structure and game mechanisms of Phase II. Building on the idea that the game shall be flexible in the way that players could add hazards or solutions themselves, I created Phase I by myself. Moreover, based on the concept, I created the idea of the climate story book and developed it.

9.5 Facilitating the uptake of no-regrets actions for disaster preparedness by citizens

This chapter firstly, demonstrated the existing gap between theory and practice along by means of flood action groups in Germany. Secondly, this chapter focused on methods and tools to bridge the knowledge-action gap. Overall, practical examples supporting the facilitation of no-regrets actions were presented. This included flood action groups as facilitators for local disaster preparedness (Section 9.1), a tool to facilitate knowledge gathering on potential no-regrets actions by making scientific knowledge more accessible to citizens (Section 9.2), and two tools focusing on bridging the knowledge-action gap through gamification (Sections 9.3 and 9.4).

This section aims to summarise the main insights of this chapter in regard to the facilitation of the uptake of no-regrets actions to enhance citizens disaster preparedness under uncertainty. The main findings, lessons learnt, challenges, and opportunities are discussed in the following.

Bridging theory and practice. Based on the discussion with German flood action groups, it can be summarised that their value is not being acknowledged nor are they integrated into local risk management by local authorities to date. This discussion unveiled one major challenge of bridging theory into practice. Hence, it can be concluded that for using the potential of flood action groups as communicated in research, more work is needed to bridge scientific theories and concepts (e.g., collective governance or multi-directional communication) into practical application. Overall, it is needed to provide them a natural (coming from the real life needs and experience) and legislative position in the disaster risk governance landscape. One

step towards this direction would be ensuring that (smaller) municipalities gain expertise, and financial resources needed to enable active participation in an effective and multi-directional manner. However, an additional challenge may be the acceptance or believe that involving citizen (groups) can be of advantage for local management despite potential disbenefits of e.g., resource intensity.

Making scientific knowledge accessible. To take action, it is important to have adequate knowledge. This may not always be the case as citizens have different expertise. Therefore, one way to facilitate action uptake is to provide information on potential actions. In the case of Nature-based Solutions, this may require more information than for reparking a car. Scientific literature on NBS is advancing at a fast pace but is not always understandable to citizens. The NBS Toolkit presents one example of how scientific knowledge can be bridged to citizens; thus, the lack of knowledge does not become a major barrier for their disaster preparedness. Of course, this toolkit may be primarily used by people who are actively searching for information and hence, by people with a climate change action mindset. One major drawback of these kind of tools can be that they are difficult to discover in the vast number of platforms available.

Facilitating practical application. Flooding experience constitutes one major facilitator for the uptake of no-regrets actions including founding flood action groups. As we have seen, flood action groups may not always be very successful in motivating other citizens to take action. However, building on scientific knowledge, these initiatives could play a valuable role in facilitating the uptake of no-regrets actions for local disaster preparedness. Using technological tools to bridge the knowledge-action gap and as a facilitator for no-regrets action uptake, the gamified app and serious game were two examples for bridging this gap by focusing on the motivation factor. Hence, they are providing an opportunity to engage citizens who might be less eager to take preparedness actions. Furthermore, these tools integrate the idea of turning citizens into knowledge creators or sharers which is further known for bridging the knowledge-action gap. However, here, the main challenge is also to raise awareness on the existing tools; thus, they are actually used.

Overall, it can be summarised that there is no single tool or method which can facilitate the uptake of no-regrets actions, especially, also considering individuals' own preferences, capabilities, resources, habits, and much more. Therefore, it is necessary to facilitate no-regrets actions through various methods and tools as well as through policy and financial support.

10 Discussion

The overarching aim of this thesis was to *identify ways that encourage citizens to prepare for a future where the occurrence of hazards is deeply uncertain*. This aim was supported by the following three research objectives:

Objective I Explore factors that shaped individual disaster preparedness action and inaction in Germany in 2021.
Approach towards the objective: A survey was conducted in Germany (Chapter 3) and the results of it are discussed in the three empirical chapters (4-6).

Objective II Understand how and to what extent the no-regrets approach can be adopted to guide citizens towards disaster preparedness under uncertainty.
Approach towards the objective: Two frameworks (Chapter 7-8) were developed in regard to the no-regrets approach.

Objective III Identification of methods and tools to facilitate the uptake of no-regrets actions for disaster preparedness by citizens in practice.
Approach towards the objective: Firstly, a focus group discussion was organised focusing on flood action groups and their potential in facilitating disaster preparedness (Section 9.1). Existing theories, methods, and tools were reviewed (Section 2.3) based on which practical tools were developed (Sections 9.2-9.4) to facilitate the uptake of no-regrets actions.

In the following, each objective will be discussed along with its scientific contribution, limitations that arose, additional contributions beyond this thesis, and the overall impact of the research.

10.1 Lessons learnt from the floods in Germany in 2021

In support of Objective I, a case study was conducted focusing on flood affected areas in Germany during July 2021. From the thematic analysis of questionnaire responses by citizens, three topics emerged which extended the current scholarships on disaster preparedness. These topics were discussed in the following research articles:

- ‘Surprise floods: The role of our imagination in preparing for disasters’ (Chapter 4) published in *Natural Hazards and Earth System Sciences by the European Geosciences Union*
- ‘Risk social contracts: Exploring responsibilities through the lens of citizens affected by flooding in Germany in 2021’ (Chapter 5) published in *Progress in Disaster Science*
- ‘Turning regret into future disaster preparedness with no-regrets’ (Chapter 6) submitted to *Natural Hazards and Earth System Sciences by the European Geosciences Union*

Contribution to scientific knowledge. The research article on the role of imagination in disaster risk management (Chapter 4) has filled a scientific gap by revealing evidence on the influence of imagination in disaster preparedness. Imagination is often mentioned in media (The News International, 2022; United Nations, 2023) and sometimes also in research studies (Kuhlicke, 2010) but its influence on disaster behaviour has not been explored in more depth. This research article generalised research insights by building a theory on the role of imagination in disaster preparedness. In particular, the results unveiled that a lack of imagination of severe hazards can hamper individual disaster preparedness. Moreover, the article refines the theory of risk perception by providing evidence on the relationship of imagination and risk perception.

The second research article (Chapter 5) applied the social contracts framework (Blackburn & Pelling, 2018) in a novel way to situate differing perspectives on disaster risk governance responsibilities. The insights into perceived and legal-institutional risk social contracts emphasised implications for policy and practise to clarify roles and responsibilities as well as the need for moving towards collective responsibility (Ansell & Gash, 2008; Emerson et al., 2012) in disaster risk governance. Overall, this article advanced scientific evidence on the applicability of the framework on social contracts. Simultaneously, it underlined the need for an extension of the concept which further includes the aspect of how differing social contracts can be aligned to achieve an agreed arrangement of disaster risk management and governance responsibilities.

By date, decisions, actions, and inactions of citizens on disaster preparedness have not been explored from the perspective of regret. The research article (Chapter 6) advanced the scholarship on regret of decision-making (G. Feldman & Albarracín, 2017; G. Feldman & Chen, 2019; J. Feldman et al., 1999; Sunderrajan & Albarracín, 2021) by introducing the concept to disaster science. This unique perspective on disaster preparedness provided evidence on actions that were not regretted by citizens which has been an important input for the development of the no-regrets framework for citizens in Chapter 7.

Relevance beyond the case study area. Overall, the theories extended or derived from the case study are relevant in scientific context as these are likely not restricted to the German context because of their psychological/cognitive focus.

In particular, the limitation of imagination and its influence on individual disaster preparedness was observed in different areas of the case study; thus, a theory could be built based on the results. In general, imagination is a cognitive process building on our 'memory, visualisation, spatial navigation, and episodic future thinking' (Jung et al., 2016). The ability to imagine differs between individuals depending on these intrinsic elements. These differences are likely observed globally as they are stemming from cognitive abilities and personal experiences rather than cultural aspects. Hence, this theory can be of global relevance for disaster science and is less restricted in terms of generalisation. Nonetheless, to strengthen the theory on the role of imagination in disaster context, further research is recommended using different qualitative research methods and extending the case study area to other regions and countries.

Similarly, the study on regret of preparedness (in)action is not directly linked to spatial context due to its psychological focus. For instance, the derived theory that individuals are rather regretting their inactions can be further explored outside of the study area. In contrast, generalisations on individual decision-making for (not) taking actions could be highly context specific considering e.g., risk governance structures.

In the case of the findings from the empirical study on risk social contracts, the findings are highly context specific considering the culture, institutional structures, norms, etc. within the case study area. Hence, the findings are rather providing implications for practitioners and policymakers within the case study area and

eventually can be applicable for other areas within Germany since risk management structures are relatively comparable within the country. This study can be further relevant for a comparison of risk management and governance structures in other countries.

From a methodological perspective, the application of the social contracts framework and identified limitations of it are not spatially or culturally sensitive; thus, these insights can be relevant for any future study applying this lens. Furthermore, the questionnaire has the potential to be replicated in other areas within or outside of Germany as the questions are not limited to the case study. Eventually, small adjustments on quantitative questions would need to be made in terms of e.g., communication channels or living conditions in case these differ from Germany.

Implications for practitioners and policymakers. The findings of the case study are not only relevant for science but also for practitioners and policy makers.

Firstly, the findings on imagination propose the need for improving forecast and warning communication to trigger imagination of potential hazards. In particular, the findings indicated that visual supports such as videos, photos, or virtual reality can trigger imagination in a short-term. This suggests implications for improving the communication but requires further research and evidence to ensure the maximal impact of communication. From a long-term perspective, the research underlined the need for cultivating imagination over time to enable citizens to imagine different future scenarios (e.g., climate change scenarios). In this regard, the findings recommend integrating the cultivation of imagination into practice. For instance, through local workshops using narrative approaches.

Secondly, the findings in regard to social contracts in Germany and the lacking interactions between citizens and local authorities include strong recommendations for implications on a practical level but also on policy level to support practical application. To enhance the application of the findings, a policy brief is planned to be developed further including recommendations for practice which were highlighted in Chapter 5.

Limitations of the research. The philosophical research approach, data collection, and analysis had certain limitations on the findings of the empirical study.

Firstly, the adoption of a case study approach inherits limitations regarding the generalisation of results considering that the results are highly place specific. However, the case study approach was chosen to be most suitable for the exploratory aim of this thesis in regard to the flooding event. Based on the case study results theories could be built or existing theories could be extended which are of global relevance in disaster science. However, as indicated earlier, the relevance of specific findings related to social contracts may be limited to other areas in Germany as the perceived social contracts are highly context specific and the legal-institutional social contracts are limited to the German governance structures. Furthermore, these findings are highly relevant to support policy and practice in the case study area and in Germany, in general. For international research, these findings could be used for comparison purpose.

Secondly, the questionnaire was designed to gain an insight into the perspectives of citizen on the flooding event. For this purpose, the application of a questionnaire was very suitable as it enabled the identification of emerging themes across differently affected areas in Germany. However, the method did not always allow to reach an in-depth understanding on the reasoning of the findings. For instance, why did citizens decide on taking these specific actions, what else helped them to imagine the approaching flood, or why did they perceive roles and responsibilities the way they did. In this regard, it can be summarised that the questionnaire was successful in identifying important themes which emerged across the case study area. However, for the purpose of gaining a deeper understanding, the questionnaire could be combined with different qualitative tools such as semi-structured interviews or focus groups.

Thirdly, potential biases may occur regarding the design of the questionnaire as well as the data analysis and interpretation due to my personal background. As broadly discussed in the positionality and bias statement in Chapter 3, growing up and living in Germany for more than 20 years has shaped my personal view on culture, politics, norms, and more, which can have influenced the empirical study unintentionally. To counteract this bias, I aimed to be transparent in presenting my research approach and the analysis/interpretation of the data. For instance, by including many quotes along the interpretations that support the derived theories. Nonetheless, my background may have a limiting effect on the findings of this research.

Contributions towards the objective beyond this thesis. Throughout the past years, I presented some results of the survey at different national and international scientific conferences. In most cases, the audience encompassed scientists conducting research on the same flooding event. Through these presentations, it was easy to network with other scientists to discuss our findings which were sometimes comparable, sometimes complementing, or new to another. In this regard, the presentations supported the awareness raising on the survey findings. Moreover, the discussions helped to me to look at the findings from different perspectives. The presentations included the following:

- *KAHR Conference*. The first KAHR conference was held in 2022 and was organised by the German KAHR project[8] focusing on the reconstruction after the floods in Germany in 2021. I presented twice online: in 2022, a 20 min presentation on 'Citizen's perceptions on the German flooding event in 2021'; and in 2023, a 10 min presentation on 'Individual and community resilience with no-regrets: a way forward'.
- *EGU General Assembly 2023*. As part of the session 'Resilience building and risk reduction: Assessments, frameworks, tools and experiences' which was primarily focusing on the German flooding event in 2021, I hold a 10 min presentation in person on 'How citizens perceived the German flooding in 2021 and which actions they took' (Ommer et al., 2023). At the end of the session, a great discussion was ongoing on different findings and ways forward. The discussion of this presentation paved the way to the research article on risk social contracts (Chapter 5).

  The conference abstract was not added to the appendix but is available at: https://doi.org/10.5194/egusphere-egu23-12821.
- *European Climate Change Adaptation (ECCA) Conference 2023*. As part of this international conference my poster on 'Towards no-regrets: lessons learnt from the flood in Germany in 2021' was exhibited.
- *International Conference on Climate Risk, Vulnerability and Resilience Building 2023*. At this conference organised by UNESCO, my poster on 'Towards citizen and community resilience: lessons learnt from the German flooding in 2021' was exhibited.

[8] https://www.hochwasser-kahr.de/index.php/de/

- *Woche der Klimaanpassung*. A national week for climate change adaptation was organised in Germany in September 2023[9]. Within this framework, I organised one online presentation and two online workshops. The presentation was focusing on communicating the results of the survey to citizens. While the two workshops were aimed to offer a space for exchange between flood action groups on the two topics: 1) flood action groups and their work and challenges, and 2) individual flood preparedness. These two workshops were well received and supported an effective interregional exchange between flood action groups. The insights gained from these sessions were discussed in Section 9.1. Overall, the participants were very happy about this exchange opportunity and therefore, I organised a second (informal) meeting in January 2024.

Impact of the research. Due to the recent submission and publication of the research studies, only little is known about the academic impact of the research (articles). Overall, the research paper on imagination was picked up by the research community very quickly. Following the publication of the pre-print, my co-authors and me received many positive responses but also indications for future practical application, for instance, the potential usage of VR in disaster management at the European Commission's Joint Research Centre. In practice, the results from the study were translated into a new service[10] by KAJO (the company I am working for) and its daughter company simON-XR. Follow-up research was successfully introduced into a new EU-funded project connecting imagination to impact-based forecasting and emergency plans for sensitive infrastructure.

The article on disaster risk governance responsibilities was used to support a political/legal analysis of EU Flood Governance picking up the needs of rebuilding trust and creating joint responsibilities.

Overall, the research findings of the three studies in combination with the proposal writing of CYGNUS (inCreasing capacitY and manaGemeNt before, dUring and after high impact low probability events) have been initiating and shaping the no-regrets framework (Chapter 7). Especially, the article on regret was the main driver for this new scientific framework. Moreover, some findings of these articles were feeding into the

[9] https://zentrum-klimaanpassung.de/wdka23

[10] https://www.sim-on.space/crisis-management-company

new project proposal SWALLOW (Severe Weather Awareness fellow submitted to HORIZON-CL3-2023-SSRI-01-02) for community and impact-based early warning systems. The research results will also be applied in the EU funded projects focusing on development of multi-hazard early-warning system for Europe (MedEWSa) and community resilience in Africa (ALBATROSS).

The online and in-person presentations were very successful in sharing the survey results with scientists and practitioners working in this research field and on the same case study area. Whereas the workshops as part of the 'Woche der Klimaanpassung' have been very impactful not directly in an academic way but rather in facilitating an exchange of experiences, challenges, and solutions to overcome these challenges between flood action groups from different regions in Germany. The impact became obvious in the second meeting in January 2024 when participants mentioned that they implemented solutions suggested by other groups in the previous meeting which helped them to advance with their ambitions and communication with the local municipality.

10.2 Toward citizens' disaster preparedness under uncertainty with no-regrets

Building upon the results and real-life needs that emerged from Objective I, Objective II was focusing on framing no-regrets solutions to address these needs:

- 'Being prepared for an uncertain future with no-regrets: A framework for individual and collective flood preparedness' (Chapter 7) submitted to Progress in Disaster Science
- 'Quantifying co-benefits and disbenefits of Nature-based Solutions targeting Disaster Risk Reduction' (Chapter 8) published in the *International Journal of Disaster Risk Reduction*

These two review articles targeted the following key research question: how can uncertainty be circumvented to encourage citizens to prepare for disasters without regretting their actions?

Contribution to scientific knowledge. In line with the global ambition of shifting towards proactive disaster risk management (UNISDR, 2015), the review article (Chapter 7) advances the scholarship on individual disaster preparedness by focusing

on decision-making under uncertainty to promote a (long-term) preparedness behaviour. Furthermore, building on the results of the Objective I and the discourse on decision-making under uncertainty (Courtney et al., 1997; Marchau et al., 2019), this article bridges the no-regrets approach to citizens' individual and collective preparedness. This framework contributes to theoretical understanding of preparedness actions for citizens by categorising them into different levels of uncertainty. Going beyond existing no-regrets literature in the climate change and disaster discourse (Auld et al., 2006; Hallegatte, 2009; Heltberg et al., 2009; Plume, 1995), this framework extends current criteria for no-regrets actions by integrating interdisciplinary theoretical knowledge on citizens disaster preparedness. The new criteria include: 1) the need for actions being easy-to-implement which shall anticipate the barrier to preparedness of low self-efficacy or coping appraisal (Bubeck, Botzen, & Aerts, 2012); 2) co-benefits which are distinguished from direct benefits (Ommer et al., 2021; Sunderrajan & Albarracín, 2021); 3) cost-effectiveness in respect to existing literature which indicates that solutions are increasingly decided on if they are effective in reducing the risk (Anderson et al., 2022); and 4) a collective criterion which shall encourage collective actions which in turn can trigger individual preparedness motivation (Dittrich et al., 2016; Gaillard, 2010; Kuang & Liao, 2020; Soetanto et al., 2017; Thaler & Seebauer, 2019).

The review article on co-benefits and disbenefits of Nature-based Solutions (Chapter 8) has been filling the scientific and practice gap of quantitative pre-assessments of the impact of NBS. Previous approaches have only qualitatively estimated the potential co-benefits (Liquete et al., 2016; NWRM, 2015a; Raymond, Frantzeskaki, et al., 2017; Watkin et al., 2019; Wendling & Rinta-Hiiro, 2019). This article merged existing quantification methods from other research disciplines for selected indicators and hence, advanced the NBS scholarship. In addition, the framework highlights the need of acknowledging and pre-assessing potential disbenefits of NBS which have been largely neglected in research by the time of the publication of the article.

Limitations of the research. The main limitation of the review article on the no-regrets approach was that a systematic review of actions was not applicable due to the fact that preparedness actions which can be taken by citizens were not named as no-

regrets actions (interventions, measures, etc.) but rather under various different umbrella terms. The main umbrella terms were identified, and a non-systematic review was performed utilising these terms. However, this non-systematic review influenced the resulting list of actions in two ways: 1) the list is not holistic, and 2) the list of actions indicates a bias towards disaster preparedness in developed countries. To address these limitations, the no-regrets framework will be adopted in existing projects in Europe and in a new project with focus on needs-based adaptation in Africa.

The framework for quantifying co-benefits of Nature-based Solutions provides a large collection of pre-assessment methods and formulas. However, the main practical limitation of this framework is that a tool would be needed combining all these methods and formulas to enhance the adoption of pre-assessment by practitioners or citizens who have limited modelling knowledge and capacities.

Contributions towards the objective beyond this thesis. In support of the Objective II, the following additional work performed during my PhD needs to be considered:

- *CYGNUS* (increasing capacity and management before, during and after high impact low probability events) proposal to HORIZON-CL3-2022-DRS-01-02. This project would have thematised high impact low probability events, conceptualising these events, developing a systemic framework for assessing their risk and cascading hazards, building a decision-support toolbox, and scenarios. As part of this proposal writing, I have been familiarising myself with the no-regrets approach and forming the idea on adopting it for the citizen's level. I have been part of the core writing team of this project proposal and hence, working on shaping the consortium, the focus of the project, and the structure of the proposal as well as the writing part itself.
- 'Challenges for a Better Use of Crowdsourcing Information in Climate Emergency Situational Awareness and Early Warning Systems' (Kalas et al., 2024). This book chapter looks at different citizen-generated information collection and analysing methods such as crowdsourcing, crowdsensing, and social media analysis. This book chapter has been a base work for my ongoing work with crowdsourcing (see next contribution). Within this chapter, I have

been primarily performing the literature review parts and supported the writing and reviewing of the other parts.

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- *Crowdsourcing actions*. In support of the no-regrets framework and (initial) list of actions for flood preparedness, I created a crowdsourcing campaign to collect more actions (also for different hazards). This crowdsourcing campaign was developed with the ambition to collect actions from different areas around the world to avoid biases and gain a more holistic picture on local, traditional, and indigenous practices. The crowdsourcing campaign is open and accessible for everyone (who has access to internet). As a first dissemination step, the campaign will be promoted within the EU-funded I-CHANGE project[11] to gather actions on different hazards from the participating pilot sites and other partners. In a second step, the campaign will be promoted outside of the project and in other projects such as EU-funded ALBATROSS with a regional focus on Africa.
- *Supporting individual and collective disaster preparedness from (sub)national level*. As part of the EU-funded MedEWSa project[12] on Early Warning for All, I performed a literature review on interventions, practices, etc. to support community resilience building and disaster preparedness. This work has been complementary to my research which primarily looks at the citizen's perspective. Hence, I use the theoretical knowledge I gained from Objective I and II to suggest ways in which municipalities or governments can support the community resilience building.
- *Policy recommendations for climate change and health*. As part of the EU-funded TRIGGER project[13], I have been engaged in the policy review on health impacts of climate stressors. Similar to the findings of Chapter 7, the outcomes of the analysis suggested the need for better acknowledgement and integration of mental health impacts. Complementing to this, this thesis highlights the need for preparedness actions to minimise potential mental health impacts. Another result of the policy review was that it is important to also consider

[11] https://ichange-project.eu
[12] https://www.medewsa.eu
[13] https://project-trigger.eu

intermediate or cascading hazards (e.g., house roof collapses due to storm, or landslide triggered by heavy precipitation) for which preparedness may be necessary. My part in this review was the analysis of the intermediate results of the text mining exercise on selected policy documents.

  - *EGU General Assembly 2024*. As part of the session 'Climate, Extremes, and Health: Mapping Risks and Quantifying Impacts on Population Health', our results of the policy review were presented: 'Health integration in climate-related policies: evidence and gaps in the EU policy context' (de Luca et al., 2024).

    The conference abstract was not added to the appendix but is available at: https://doi.org/10.5194/egusphere-egu24-20465.

- *Everything around Nature-based Solutions*. As part of the EU-funded OPERANDUM project[14], I have been involved in various research and technical activities on Nature-based Solutions which are introduced in the following:

  - *EGU General Assembly 2021*. As part of the session 'Nature-based solutions for hydro-meteorological risk reduction', I hold a 3 min online presentation on 'Quantifying co-benefits and potential disbenefits of NBS for Disaster Risk Reduction: a practical framework for ex-ante assessment' (Ommer et al., 2021). This presentation was introducing the framework presented in Chapter 8. At the end of the session, a few people contacted me to follow up on the framework.

    The conference abstract was not added to the appendix but is available at: https://doi.org/10.5194/egusphere-egu21-7874.

  - *'Evaluating the impact of nature-based solutions: A handbook for practitioners Chapter 7: Data requirements'* (European Commission, 2021). This chapter of the handbook dives into monitoring and evaluation methods for assessing the impact of Nature-based Solutions. In this sense, it is complementing to Chapter 8 (of this thesis) which focuses on the pre-assessment of potential impacts. As part of this handbook chapter, I have been co-writing the sections on citizens science as well as the subsection 7.3.1 on quantitative, qualitative, and map-based surveys.

[14] https://www.operandum-project.eu

The handbook was not added to the appendix but is available at: https://op.europa.eu/en/publication-detail/-/publication/d7d496b5-ad4e-11eb-9767-01aa75ed71a1.

- *'A nature-based solution selection framework: Criteria and processes for addressing hydro-meteorological hazards at open-air laboratories across Europe'* (Gonzalez-Ollauri et al., 2023). This article is closely related to the NBS Toolkit which I developed (Section 9.2) because it discusses the NBS selection criteria which were partly integrated into the toolkit. I contributed to the literature review on the selection criteria and the final review of the article.

  The co-authored article was not added to the appendix but is available at: https://doi.org/10.1016/j.jenvman.2022.117183.

- *'Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies'* (Debele et al., 2023). This article presents the NBS catalogue and its framework which we have developed within the project. As part of this overall framework, Chapter 8 of this thesis presents the framework for the co-benefit classification of the NBS catalogue. Within this article, I have been developing the hazard and multi-hazard classifications and co-developing the co-benefit and ecosystem classifications. Furthermore, I have been involved in the reviewing process.

  The co-authored article was not added to the appendix but is available at: https://doi.org/10.1016/j.scitotenv.2023.165824.

- *'Reducing hydro-meteorological risks through Nature-based Solutions: A comprehensive review of enabling policy frameworks in the European Union'* (Amirzada et al., 2023). This article encompasses a policy review on Nature-based Solutions with a European perspective. Looking from a legal perspective at Nature-based Solutions, this work has been indicating that NBS may have shorter permitting paths and therefore, may be easier-to-implement (supporting the idea of NBS being no-regrets actions). I have been contributing to parts on the texts on permitting path and the NBS catalogue which was used for the analysis as well as reviewing and editing the article.

The co-authored article was not added to the appendix but is available at: https://doi.org/10.1016/j.nbsj.2023.100097.

Impact of the research. The framework for no-regrets actions was adopted within the EU-funded I-CHANGE project to guide citizens in climate change mitigation and adaptation action taking. One example of the adoption of the framework is the gamified app presented in Section 9.3. This app integrated the criteria and concept of no-regrets actions (as outlined in Chapter 7) to guide citizens in reducing their environmental footprint by taking small steps (no-regrets actions). The collection of no-regrets actions for flood preparedness will be displayed on the project's citizens4climate dashboard[15] and the crowdsourcing campaign will enable the growth of this initial collection, also encouraging contributions for other hazards. Similarly, in the future, the collection and crowdsourcing campaign will be promoted within new EU-funded projects: climate change adaptation in Africa (ALBATROSS) and the resilience of buildings in Europe (RETIME).

The developed NBS framework for quantifying co-benefits of Nature-based Solutions has been influencing other scientific research which can be seen through an increasing number of citations. Furthermore, the theoretical knowledge was integrated into other articles of the OPERANDUM project. The Nature-based Solutions review article was designed as a practical framework; thus, the pre-assessment methods can be taken up by project managers.

10.3 Facilitating the uptake of no-regrets actions

Chapter 9 discussed different methods and tools to motivate citizen taking preparedness actions addressing the Objective III and responding to the third research question: *how can citizens' disaster preparedness under uncertainty with no-regrets be facilitated in practice?* In particular, Chapter 9 focused on

- Flood action groups as facilitators for local disaster preparedness (Section 9.1)
- The NBS Toolkit - a tool to facilitate knowledge gathering on potential no-regrets actions by making scientific knowledge more accessible to citizens (Section 9.2)

[15] https://citizens4climate.com

- ChallengeYeti - an app to bridge the knowledge-action gap and facilitate the uptake of no-regrets actions through the gamification as a motivational factor (Section 9.3)
- Our Climate Story - a serious game building on the participatory concept wrapped in a gaming environment to facilitate disaster knowledge creation and sharing by citizens (Section 9.4)

Contribution to scientific knowledge. This thesis highlighted that theoretical knowledge and approaches require a stronger support for their practical application as the focus group discussion with flood action groups underlined. In addition to this, Chapter 5 already indicated the gap between science and practice which needs to be addressed.
Furthermore, the tools presented in Sections 9.2-4 can be used as examples for bridging scientific knowledge to citizens and addressing the knowledge-action gap. Yet, to strengthen the theoretical contribution, the impact of these tools (e.g., on behavioural change) needs to be assessed in the future.

Limitations. The main limitation of the serious game and gamified app are that they have not been tested and evaluated yet. This will be performed throughout 2024. Once more insights are available on how these two tools can facilitate the uptake of no-regrets actions, it is planned to publish the results in research.
The NBS Toolkit is aiming to provide recommendations on NBS across Europe. However, this large-scale ambition has been facing limitations towards fine resolution datasets as these have had an unfeasible data storage size and therefore, the suitability mapping outputs are rather coarse. Yet, having in mind that this tool is designed for pre-assessment purpose only, the coarse outcomes are still in an acceptable level.

Contributions towards the objective beyond this thesis. In support of my work on bridging science to practice and citizens in this thesis, the following additional work performed during my PhD need to be considered:

- *I-CHANGE project*. The project is working on the idea of crowdsensing to increase the awareness on weather, air pollution, and environmental changes

by co-producing the knowledge (data and the analysis of it) which shall introduce behavioural changes. As part of this project, the ChallengeYeti app and the Our Climate Story serious game were developed. The development of these and of the project's citizens4climate dashboard have influenced my work by adding the component of behavioural change and bridging the science-technology nexus to citizens. I have been working in many tasks around these tools but especially also leading the work package on exploitation which again wraps my mind on how the project results can be taken up by others; thus, bridging science to science but also to technology, practice, policymakers, and citizens.

- *INSTIL workshop*[16] as part of the eScience conference 2023. The workshop was aimed at discussing citizen science activities and serious games within this more technical conference. The workshop helped to promote the bridge between science and citizens and how technology can be used as a facilitator. I have been co-organising this workshop and its reviewing process.
- *Blog - put another way*[17]. With the main ambition to put [science] in another way that it is understandable and usable by everyone, I developed a blog. The idea for the blog arose while analysing the responses of the survey and thinking about how the governance system in general and the preparedness of citizens could be improved, I felt the need to communicate these research findings not only to other scientists but also to citizens. In this regard, the blog was developed primarily for science communication purposes but, to date, is still at its beginnings. After submitting this thesis, I am planning to continue more intensively with the blog.
- *GeoIKP*[18] – a platform for Nature-based Solutions. The NBS Toolkit is one element of the GeoIKP. This platform aims to introduce Nature-based Solutions to a broad range of audience and communicate the project's research outputs. Acknowledging that the content needs to be communicated differently - depending on the audience - it includes tailored information and tools for citizens or associations such as an NBS catalogue with case studies around the

[16] https://www.instil-science.eu
[17] https://www.putanotherway.org
[18] https://geoikp.operandum-project.eu

world or a story board where citizen and citizen groups can share their experiences of NBS projects with another. I have been primarily conceptualising the elements, functionalities, and content of this platform with the help of other project partners.

  - *EGU General Assembly 2021*. As part of the session 'Nature-based solutions for hydro-meteorological risk reduction', I held a 5 min online presentation (as a replacement) on the GeoIKP platform with the focus on 'Nature-Based Solutions for Hydro-Meteorological Hazards: the OPERANDUM Database' (Leo et al., 2021).

    The conference abstract was not added to the appendix but is available at: https://doi.org/10.5194/egusphere-egu21-1380.

- *NBS Toolkit*. The NBS Toolkit was already presented in Section 9.2 but in support of it, I have written an article on the methodology:
  - *'The impact of spatial resolutions on Nature-based Solution suitability mapping for Europe'* by Joy Ommer, Jessica, Neumann, Sasa Vranic, Milan Kalas, Laura S. Leo, Silvana Di Sabatino, and Hannah L. Cloke. This article presents the research methodology used for the NBS Toolkit but specifically, discusses the influence of spatial resolutions on the output of the suitability mapping which is used to recommend suitable NBS in the NBS Toolkit.

    The article was published in the Special Issue 'GIS-Based Environmental Monitoring and Analysis' of the Journal Applied Sciences (MDPI) in June 2024. The published version is available in Appendix 4.

Impact on practice. Establishing the flood action group forum was successful as participants from different regions around Germany could share their experiences and challenges. Moreover, this cross-regional exchange helped the groups in discussing different solutions or pathways to overcome their challenges. In other words, they could help each other based on their previous experiences. As the meeting was perceived as very valuable by the participants, a second informal meeting was organised by me and therefore, is not discussed in this thesis. In this meeting, it was mentioned that suggestions which were made in the past meeting were integrated by one group and reached a positive impact.

The NBS Toolkit supports practitioners to receive recommendations on NBS including their co-benefits which can play a major role in their decision process; thus, enable a faster uptake. Similarly, the tool is being used (in combination with the crowdsourcing tool) as part of a university program in Slovakia.

The serious game and gamified app received initially very good feedback and will be tested within and outside of the project's consortium soon. To date, we received several requests from outside of the project to use the serious game in schools or workshops organised for teenagers as well as in organisations working with people with disabilities.

10.4 Recommended next steps

The outcomes of this thesis indicated several needs for future research, policy, and practice. The main recommendations are as follows:

Trigger and cultivate imagination. Imagination was found to be influencing risk perception (Chapter 4) and therefore, citizen's disaster preparedness motivation. Considering the deep uncertainty around the future, it is needed to develop and imagine different scenarios. In this regard, more research is suggested on how imagination of different futures can be cultivated in a long-term perspective. In addition, to support warning interpretation and risk communication in general, more research is needed to identify ways to assist our imagination in creating mental pictures of hazard scenarios. In other words, how can imagination be triggered in short-term through weather forecasts and warnings. In practice, workshops can be organised focusing on future visioning, developing storylines. Furthermore, using different types of arts i.e., in exhibitions, imagination of disasters can be cultivated. As part of some projects, we will be working with virtual, extended, and augmented realities to trigger and cultivate the imagination of severe hazards.

Bridge the gap between science and practice. Chapter 5 showed that roles and responsibilities in disaster risk management are not clear and perceived differently. Furthermore, the study showed that responsibilities are segregated in the way that they are either ascribed to citizens or others and only very few joint responsibilities were mentioned. As a conclusion of this research article, the need was raised to

strengthen policies and enhance practice to ensure collective flood governance and to bridge the interface between citizens and authorities with flood action groups or similar. However, talking to flood action groups within the forum, it became obvious that there is a gap between science and the actual implementation of it because the main challenge of the groups was (and still is) to reach a multi-directional communication with representatives of the municipalities. In the idea of collective governance, collaboration should be initiated by the local authorities. Yet, this is a farfetched aim since local authorities, especially in small municipalities or villages, may not have the resources, mindset, or skills to start this collaboration. Therefore, interdisciplinary research may be needed to gain a better understanding of the underlying factors preventing collaboration initiation and how policies and practice can be designed more effectively to achieve this objective.

Recommendations for NBS. To date, the NBS Toolkit is very flood oriented and was developed for the European region. One next step will be to expand the pool of NBS for recommendations to other hazards. Another step will be the expansion of the toolkit to the African region within the ALBATROSS project. Within the RETIME project, we will adjust the toolkit for creating recommendations on building resilience. In addition, we will be developing a cost-benefit tool for climate change adaptation which might be merged with the toolkit.

Focus on long-term preparedness. The review of no-regrets actions (Chapter 7, Appendix 3) highlighted that most actions can already be taken today! Usually communicated disaster preparedness actions are more focusing on actions which may be taken after a forecast indicates a potentially approaching hazard. However, in this thesis, I have been arguing that it is needed to shift preparedness to a long-term perspective meaning that we should be focusing on increasing our knowledge and capabilities to be able to cope with a hazard one day. In fact, this reflects the definition of disaster preparedness (UNDRR, 2017). Of course, it is important to also take emergency preparedness actions, but we need to start preparing basically now while accepting the deep uncertainty.

Enrich the no-regrets action catalogue. The no-regrets actions collected to date (Appendix 3) are biased towards developed countries; thus, one ambition is to enrich the list with local, traditional, and indigenous knowledge and practices through crowdsourcing. In support of this, I will be promoting the crowdsourcing campaign in ongoing and future projects that I am working on.

Actively facilitate preparedness action taking. One objective of this thesis was to design different pathways to facilitate the uptake of no-regrets actions to prepared for an uncertain future. Different pathways were developed and discussed but this will not be sufficient to enhance preparedness of citizens. One important step will be the facilitation through collective actions and social learning. However, this still requires additional initiation and facilitation in areas that did not experience a specific hazard yet.

Focus on the motivational factors. The scholarship on disaster preparedness is usually focusing on identifying the barriers to preparedness motivation but not primarily looking at the motivational factors. In contrast, one ambition of this thesis was to approach the knowledge-action gap by focusing on motivational factors (Chapter 9). For instance, integrating game elements; focusing on actions which are of low costs, entailing benefits and shall be easy-to-implement; considering collective action as a motivation; turning citizens into knowledge creators and sharers; or encouraging imagination. Since, I do not have (enough) evidence on the success of this approach yet, one recommended next step is to test and evaluate how these motivational aspects can support action taking which I am planning to do in different projects after this thesis. Especially, developing the ChallengeYeti app with a focus on disaster preparedness.

Enhance psychological preparedness. One of the main shortcomings that was identified through the review of no-regrets disaster preparedness actions (Chapter 7) is that actions discussed in disaster literature are almost exclusively focusing on the physical preparedness by neglecting the importance of psychological preparedness. In this context, physical preparedness aims at reducing potential physical health impacts as well as damages to i.e., buildings, infrastructure, or disruption of services.

While the psychological preparedness focuses on the preparedness to deal with stress situations which disaster situations can cause. In particular, this type of preparedness aims to increase capabilities to mentally cope with the disaster and its impacts, and to recover from them. In this regard, more interdisciplinary research is needed to merge psychological and cognitive disciplines with disaster science. This shortcoming was also mirrored in the review of European climate-related policies which largely neglect mental health impacts or, if included, they do not specify these nor provide anticipatory suggestions. Hence, this topic needs to be increasingly integrated into policies related to disasters and climate change. In practice, it is of importance to promote psychoeducational workshops that can help preparing for emergency situations (whether disaster related or similar). In this context, one major barrier that may need to be overcome is the low acceptance of the importance of the topic among citizens.

Beyond floods and preparedness. This thesis has primarily been looking at preparedness for flooding, but most of the work performed can be adopted in other hazard scholarships and disaster phases.

Firstly, the theories developed based on the empirical results are of relevance for disaster science in general. Especially theories linked to cognitive processes are likely to be relevant in the context of other hazards and hence, for disaster science in general. In particular, the imagination of hazards or the regret of preparedness (in) actions.

Secondly, implications for policy and practice derived from the empirical studies can be further generalised to other hazards. For instance, the collaborative flood risk governance can be adopted also for other hazards or risk governance overall. As indicated, this would include all phases of disaster risk management and not be restricted to preparedness.

Thirdly, as uncertainty is an omnipresent limitation for preparedness considering various hazards, the concept of long and short-term preparedness can be applied to different hazards but may be restricted to fast on-set hazards such as flooding, heatwaves, landslides, etc. Yet, the concept of no-regrets actions to support preparedness can be adopted for disaster preparedness and is not restricted to the type of hazard.

Fourthly, the questionnaire used for data collection can be adopted for case studies in other areas but also considering further hazard events. However, the adoption of the questionnaire in other case studies may be limited to 1) fast on-set hazard events, 2) recent events (e.g., maximum 2 years ago due to the loss of disaster memory), and 3) hazard events for which an early warning system was in place (independent from its performance).

Lastly, in terms of practical application, Chapter 9 presented various solutions for bridging theory to practice but also knowledge to action. These solutions are adoptable within disaster risk management and are not limited to certain hazards. For instance, citizen groups can be founded for different hazards or risk management overall. Furthermore, the concepts of the knowledge platform, app, and serious game can be broadened to various hazards and disaster risk management phases. An example is the serious game which is being developed for different cities. These city versions are localised and hence, focusing on the local hazards as well as risk reduction measures suitable for the area.

11 Conclusion

The overarching aim of this thesis was to *identify ways that encourage citizens to prepare for a future where the occurrence of hazards is deeply uncertain*. Approaching this aim, this thesis was built on three steps each representing one research question (Table 4) and objective.

Table 4: Synthesis of research questions and the chapters they were address in

Research Question	**Related Chapter**
RQ I: What can we learn from the flooding experiences of citizens to improve citizen's disaster preparedness for the future?	Chapter 3-6
RQ II: How can uncertainty be circumvented to encourage citizens to prepare for disasters without regretting their actions	Chapter 7-8
RQ III: How can citizen's disaster preparedness under uncertainty with no-regrets be facilitated in practice	Chapter 9

The first research question aimed to explore *what we can learn from the flooding experiences of citizens to improve citizens' disaster preparedness for the future*. Using an empirical approach, the case study on the German floods in 2021 highlighted three main insights related to citizens' disaster (un)preparedness: Firstly, the lack of or limited imagination of potential future hazard(s) emerged as a key determinant for risk perception and was found to be an additional barrier to preparedness motivation of citizens. Secondly, situating perceived responsibilities by citizens within legal-institutional structures, it can be summarised that citizens are highly dependent on local authorities and other disaster actors which lowers their self-responsibility for disaster preparedness. The findings of this study underlined the need for increasing collaboration between citizens and local authorities to empower citizens to act and prepare more independently and to foster their feeling of self-responsibility. Thirdly, exploring the regrets of citizens affected by flooding was used to strengthen the idea of and the need for a no-regrets approach for disaster preparedness under uncertainty. Findings from the study on imagination and regret which were generalised to theory are of high relevance for disaster scholarship and are recommended to be

studied in more depth within and outside of the case study area of this thesis. Whereas the findings from the study on flood governance are limited to the German context in terms of i.e., culture, historic flooding experiences, and legal-institutional structures and hence, are only comparable to the governance structures from other countries. Nonetheless, discussed concepts such as collaborative governance and joint responsibility can be of relevance in other areas.

The no-regrets approach was identified as a solution for the second research question *how uncertainty can be circumvented to encourage citizens to prepare for disasters without regretting their actions*. With its characteristics of robustness and flexibility, low costs and potential benefits, and the promise that actions shall not be regretted in any of the future scenarios, it was found to be a promising scientific framework for practical application as it has proven its efficacy throughout the past in different research and policy fields. In this regard, the no-regrets scholarship was extended by developing a framework for individual and collective actions for disaster preparedness under uncertainty. In response to some of the acknowledged barriers to citizens preparedness motivation, the framework was adjusted by adding more criteria: firstly, the need for actions to be easy-to-implement to circumvent doubts about the sufficiency of own capabilities to take actions. Secondly, costs were set in relation with the effectiveness in risk reduction. Thirdly, the collective action potential was recognised to enhance social learning and mutual motivation. This framework is not limited to flood preparedness but has the potential to be adopted for different hazards and also disaster risk management phases. Considering the promotional focus of no-regrets actions, especially Nature-based Solutions, a second framework was developed to quantitatively pre-assess potential co-benefits but also disbenefits of solutions, to ensure that promised impacts do not turn out to be a hoax and then be regretted.

Finally, it was discussed *how citizens' disaster preparedness under uncertainty with no-regrets can be facilitated in practice*. At first, an example of flood action groups in Germany was discussed in the context of earlier findings within the first research question. This section highlighted the gap between science and practical adoption of scientific theories. In terms of facilitating the no-regrets preparedness of citizens and

bridging the knowledge-action gap, it was found that collective action can be beneficial but cannot be the sole motivational factor. Other motivational approaches which were discussed were making scientific knowledge accessible to and understandable for citizens, creating tools to facilitate citizens in becoming knowledge and solution creators or sharers and in changing their behaviour step by step. These pathways were identified which fulfils the third objective, but more evidence on their efficacy is required in the future.

Overall, the thesis contributed to the disaster preparedness scholarship by extending the concept of risk perception with the component of imagination; advancing the evidence on the application of the social contracts framework; introducing the regrets scholarship to disaster science; extending the no-regrets scholarship to citizens and developing a framework assisting citizens in disaster preparedness under uncertainty; guiding the pre-assessment of co-benefits and disbenefits of Nature-based Solutions; and lastly bridging of the theoretical knowledge into practice with the aim to facilitate citizens' disaster preparedness.

The main limitation of this thesis was that the design of the questionnaire which did not allow any further reasoning beyond the responses provided by participants. Therefore, it is suggested to follow up on those topics (e.g., imagination or the decision pathways in preparedness contexts) that emerged from the survey with additional qualitative tools such as interviews or focus group discussions. Overall, the adoption of a case study approach restricts the relevance of some findings due to their particularity to German context. In regard to the third objective, evidence on the impact of the tools and of flood action groups on individual disaster preparedness is needed.

In conclusion, there is a need for a shift towards long-term disaster preparedness by citizens to enhance their imagination of potential hazard scenarios, and increase their knowledge, physical, psychological, and technical skills to cope with emergency situations and to recover from these. Yet, citizens need to be actively motivated, engage, and their preparedness process needs to be facilitated which can be realised through local authorities, citizen initiatives, tools, policy recognition, etc. This

motivation and facilitation process primarily needs to focus on citizens who have not experienced a hazard to date or citizens who may not even be aware that they are living in a risk area. Overall, this needs to be situated within an institutional and social context that is supportive for disaster preparedness.

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Appendices

Appendix 1: Questionnaire in German language

Erfahrungs- und Meinungsaustausch zum Hochwasserereignis in Deutschland im Juli 2021

Zunächst möchte ich Ihnen für Ihre Teilnahme an dieser Umfrage danken und Ihnen und Ihrer Familie mein Mitgefühl aussprechen, falls Sie vom Hochwasser oder anderweitigen Überschwemmungen betroffen waren.

Mit dieser Umfrage möchte ich einen Einblick in Ihre Erfahrungen mit dem Starkregen- und Hochwasserereignis in Deutschland im Juli 2021 erhalten, um zukünftige Katastrophen zu minimieren. Dies wird in der ersten Hälfte des Fragebogens thematisiert. In der zweiten Hälfte des Fragebogens, erfragen ich Ihre persönliche Meinung zum Management während des Ereignisses.

Eingeladen zu dieser Umfrage sind alle ab 18 Jahren, die im vergangenen Jahr indirekt (z. B. durch Familie oder Beruf) oder direkt von Überschwemmungen betroffen waren. Überschwemmungen können durch starke Regenfälle, über die Ufer tretende Flüsse, hohe Grundwasserstände oder überlaufende Abwasserkanäle verursacht worden sein.

Weitere Informationen:
Der Fragebogen enthält 26 Fragen und das Ausfüllen des Fragebogens dauert etwa 15 Minuten.
Die Teilnahme ist anonym, vertraulich und freiwillig.
Sie können Ihre Teilnahme (auch nach der Abgabe) jederzeit abbrechen, besonders, wenn diese bei Ihnen Kummer oder Stress auslöst.
Bitte beachten Sie, dass die von Ihnen eingegebenen Informationen nicht gespeichert werden, wenn Sie das Fenster vor Absendung schließen.
Mit * markierte Fragen sind Pflichtfragen.
Die Daten, die bei dieser Umfrage erhoben werden, werden gesichert aufbewahrt und können anonymisiert zur Verfügung gestellt werden, um das Katastrophenmanagement zu

verbessern.

Diese Umfrage ist Teil meiner Doktorarbeit zum Thema Katastrophenminimierung. Ich beschäftige mich mit verschiedenen Teilbereichen, wie der Minimierung von Katastrophen durch naturbasierten Lösungen, der Verbesserung von Kommunikation von Warnungen und der Bewusstseinsbildung von zukünftigen Risiken. Ich komme ursprünglich aus dem Bergischen Land und promovieren jetzt an der Universität in Reading in England und arbeite für KAjO in europäischen Projekten zur Katastrophenminimierung.

Bei Fragen oder zum Widerruf Ihrer Teilnahme können Sie sich gerne an mich (Joy Ommer) per Email (j.ommer@pgr.reading.ac.uk) wenden.

* Required

Zustimmung zur Umfrage

1. Ich habe verstanden, dass *

- [ ] meine Teilnahme anonym und freiwillig ist.
- [ ] die von mir in dieser Studie erhobenen Daten aufbewahrt werden und dass ich das Recht habe, eine Kopie meiner Daten anzufordern.
- [ ] die bereitgestellten Informationen anonymisiert zur Verfügung gestellt werden können, damit sie von anderen eingesehen und weiterverwendet werden können.

Das Hochwasser

2. Haben Sie im Juli 2021 Überschwemmungen erlebt? (Sie können mehr als eine Antwort auswählen) *

- [ ] Ja, mein Haus/meine Wohnung war von Überschwemmungen betroffen
- [ ] Ja, meine Familie/Freunde/Nachbarn waren von Überschwemmungen betroffen und ich haben ihnen geholfen
- [ ] Mein Unternehmen wurde überschwemmt
- [ ] Ja, die Überschwemmungen haben meinen Alltag betroffen
- [ ] Ja, ich war zu der Zeit im Urlaub in einer Gegend die von Überschwemmungen betroffen war
- [ ] Ja, mein Zuhause/meine Familie war betroffen, aber ich war zu dieser Zeit nicht in der Region
- [ ] Nein, ich war nicht von Überschwemmungen betroffen, obwohl es vorhergesagt war
- [ ] Nein, ich war nicht von Überschwemmungen betroffen, aber ich war als Helferin/Helfer aktiv
- [ ] Nein, ich habe keine Überschwemmungen erlebt und es wurde auch nicht vorhergesagt. Wenn Sie diese Option auswählen, können Sie direkt mit Frage 16 weitermachen
- [ ]

Other

3. Woher kam das Wasser?

- [ ] Von einem Bach
- [ ] Von einem Fluss
- [ ] Steigendes Grundwasser
- [ ] Überlaufender Abwasserkanal
- [ ] Starken Regenfällen
- [ ] Gesättigte Bodenfläche
- [ ] Other

4. Ist Ihnen etwas bekannt, was die Überschwemmungen in Ihrer Gegend verstärkt oder reduziert hat?

Was wurde getan

5. Wie haben Sie reagiert und was haben Sie getan, als Sie von möglichen Überschwemmungen erfahren haben?

6. Wie haben Sie getan als das Wasser kam?

Eigenvorsorge

7. Wie gut fühlten bzw. fühlen Sie sich auf Überschwemmungen vorbereitet?

	Sehr gut vorbereitet	Teilweise vorbereitet	Nicht vorbereitet	Ich weiß es nicht
Vor den Überschwemmungen	○	○	○	○
Während den Überschwemmungen	○	○	○	○
Nach den Überschwemmungen	○	○	○	○
Heute	○	○	○	○

8. Warum fühlten bzw. fühlen Sie sich (nicht) vorbereitet?

Warnungen

9. Erinnern Sie sich, wann Sie zum ersten Mal über die Möglichkeit von Überschwemmungen im Juli gehört/gelesen haben und wann das Wasser kam?

10. Woher und wann haben Sie Informationen zu möglichen Überschwemmungen erhalten?

	Vor dem Hochwasser	Während dem Hochwasser	Nach dem Hochwasser	Die ganze Zeit	Niemals
TV Nachrichten	○	○	○	○	○
Zeitung	○	○	○	○	○
Online Nachrichten/ Nachrichten App	○	○	○	○	○
Wetter App	○	○	○	○	○
Warn-App (z.B. NINA)	○	○	○	○	○
Soziale Medien (z.B. Twitter, Instagram)	○	○	○	○	○
Freunde & Verwandte	○	○	○	○	○
Nachbarn	○	○	○	○	○
Stadt/Gemeinde	○	○	○	○	○
Sirenen	○	○	○	○	○
Andere Quellen	○	○	○	○	○

Was Sie erwartet haben und was wirklich passiert ist

11. Für wie wahrscheinlich hielten Sie Überschwemmungen in Ihrer Gegend, als Sie zum ersten Mal davon hörten?

- ○ Sehr wahrscheinlich
- ○ Wahrscheinlich
- ○ Eher unwahrscheinlich
- ○ Unwahrscheinlich

12. Haben Sie sich vorgestellt, dass Sie von den Überschwemmungen betroffen sein würden, als Sie zum ersten Mal davon erfahren haben?

- ○ Ja
- ○ Nein
- ○ Eventuell

13. Wie haben Sie sich die Überschwemmungen vorgestellt, als Sie zum ersten Mal davon hörten?

	Extremes Hochwasser	Schlimmer als zuvor	Wie gewohnt	Kleine Überschwemmungen	Es würde keine Überschwemmungen geben/ Es gab keine Überschwemmungen
Was Sie erwartet haben	○	○	○	○	○
Wie es wirklich war	○	○	○	○	○

14. Wie haben sich die folgenden Informationen auf Ihr Handeln oder Ihr Verhalten ausgewirkt?

	Es hat mich nicht beunruhigt	Es hatte keine Auswirkungen auf mein Handeln vor und während der Überschwemmungen	Es hat mich verunsichert / verängstigt	Ich habe mit Vorbereitungen begonnen	Ich habe diese Information nicht erhalten
Die erwartete Regenmenge	○	○	○	○	○
Flüsse können über die Ufer treten	○	○	○	○	○
Hochwasserwarnung	○	○	○	○	○
Informationen über mögliche Auswirkungen vom starken Regen	○	○	○	○	○
Informationen über mögliche Auswirkungen vom Hochwasser	○	○	○	○	○
Empfohlene Verhaltensmaßnahmen	○	○	○	○	○
Hochwasser ist möglich aber nicht zu 100%	○	○	○	○	○
Fake news - gefälschte Nachrichten	○	○	○	○	○

Was würden Sie heute anders machen?

15. Stellen Sie sich vor, Sie würden jetzt eine Starkregen- oder Hochwasserwarnung erhalten: Würden Sie anders machen?

16. Stellen Sie sich vor, Sie würden jetzt eine Starkregen- oder Hochwasserwarnung erhalten: Auf welche Quellen würden Sie sich verlassen? (Sie können mehr als eine Option auswählen) *

- [ ] TV Nachrichten
- [ ] Zeitung
- [ ] Online Nachrichten/Nachrichten App
- [ ] Wetter App
- [ ] Warn App (z.B. NINA)
- [ ] Soziale Medien (z.B. Twitter, Instagram)
- [ ] Freunde & Verwandte
- [ ] Nachbarn
- [ ] Stadt/Gemeinde
- [ ] Sirenen
- [ ] Other

17. Kannten Sie Überschwemmungsgefährdete Gebiete in Ihrer Nachbarschaft vor Juli 2021? *

- ( ) Ja
- ( ) Nein
- ( ) Nicht alle

Ihre Meinung über das Starkregen- und Hochwasserereignis Juli 2021

18. Wie könnte die Kommunikation über mögliche Überschwemmungen verbessert werden? *

19. Welche Maßnahmen können Sie selbst ergreifen, um besser auf Überschwemmungen vorbereitet zu sein? *

20. Welche Probleme traten Ihrer Meinung nach während des Ereignisses im Juli 2021 auf?

21. Wie könnten diese Probleme Ihrer Meinung nach verhindert werden?

22. Was erwarten Sie von der Regierung vor, während und nach Katastrophen wie z.B. das Hochwasserereignis?

23. Wären Sie gerne stärker beteiligt in *

- [ ] Maßnahmen zur Reduzierung des Hochwasserrisikos
- [ ] Entscheidungen zum Klimawandel (inkl. Hochwasser und andere Naturgefahren)
- [ ] Katastrophenmanagement
- [ ] Warnsystemen für Katastrophen
- [ ] der Bewusstseinsbildung von Bürgern für potenzielle zukünftige Risiken
- [ ] Ich bevorzuge es mich an nichts zu beteiligen
- [ ] Other

24. Wie lautet Ihre Postleitzahl? *

25. In welche Altersgruppe würden Sie sich einordnen? *

- ○ 18-24 Jahre
- ○ 25-54 Jahre
- ○ 55-64 Jahre
- ○ 65 Jahre und älter
- ○ Ich bevorzuge es mich nicht einzurodnend

26. Wie wohnen Sie? *

- ○ In meinem eigenen Haus
- ○ In meiner eigenen Wohnung
- ○ In einer gemieteten Wohnung
- ○ In einem gemieteten Haus
- ○ Ich lebe bei meinen Eltern, etc.
- ○ Ich bevorzuge es nicht zu sagen

Sharing experiences and opinions on the flood event in Germany in 2021

First of all, I would like to thank you for your participation in this survey and if you experienced flooding, I wish to express my deepest sympathy for you and your family.

The aim of this survey is to get an insight into your experiences of the flood event in Germany in 2021 which constitutes the first half of the questionnaire and to hear your opinion on the flood event in the second half of the questionnaire.

This survey invites everyone at the age of 18 years and older who has indirectly (e.g., through family or work) or directly experienced flooding last year. Flooding may has been caused by heavy rain, rivers exceeding their banks, high groundwater levels, or by overflowing drainage systems.

Further information:
The questionnaire includes 26 questions and it will take about 10-15 minutes.
The participation is anonymous and voluntary. If you feel that the questions cause sadness or some kind of distress, you can withdraw from the survey at any time.
Please, complete the survey in one go as information you enter will not be saved when you close the window.
Questions marked with * are mandatory questions.
The data collected within this survey will be stored securely and can be made available in an anonymised format.

This survey is part of my PhD in which I focus on disaster risk reduction. As part of my PhD, I am looking at different risk reduction measures such as nature-based solutions but also at citizens' awareness of risks, their self-preparedness, and risk communication. I am a PhD student at the University of Reading (UK) and work for KAJO a company involved in European projects on disaster risk reduction.

For questions or to withdraw your participation, you can contact myself (Joy Ommer) via email (j.ommer@pgr.reading.ac.uk).

In case, you feel like needing advise or support to cope with your experiences from the flood event, you can contact social advisories (e.g., Stiftungsfamilie).

* Required

Survey Consent

1. I understand that *

- [ ] my participation is anonymous and voluntary.
- [ ] the data collected from me in this study will be preserved and that I have the right to ask for a copy of my data.
- [ ] the information provided can be made available in an anonymised way, so that they can be consulted and re-used by others.

Local flooding

2. Did you experience flooding during July 2021? (You may select more than one option) *

- [ ] Yes, my home was affected by flooding
- [ ] Yes, my family/friend/neighbor was affected by flooding and I helped them/him/her
- [ ] My business was affected by the floods
- [ ] Yes, I experienced flooding in my everyday life
- [ ] Yes, I was on holiday in an area that was affected by flooding
- [ ] My home/family was affected but I was away (e.g., on holiday)
- [ ] No, I did not experience any flooding even though it was forecasted for my village/city
- [ ] No, I did not experience any flooding directly but I worked in humanitarian response
- [ ] No, I did not experience any flooding and it was also not forecasted (if you select this option you can proceed directly to question 16)
- [ ] Other

3. Where did the water come from?

- [ ] From a small stream
- [ ] From a river
- [ ] From rising groundwater
- [ ] From full sewage systems
- [ ] From heavy rain
- [ ] Saturated soils
- [ ] Other

4. Are you aware of anything that increased or prevented the flooding in your area?

Actions

5. How did you react and what did you do when you learnt about potential flooding?

6. What actions did you take when the water arrived?

Flood preparedness

7. How prepared did/do you feel for flooding?

	Very prepared	Partly prepared	Not prepared	I don't know
Before the flood	○	○	○	○
During the flood	○	○	○	○
After the flood	○	○	○	○
Now	○	○	○	○

8. What made/makes you feel (not) prepared?

Flood information

9. Do you remember when you received information on potential flooding the first time? (How long before the water arrived?)

10. What was the source of information you found/received on (potential) flooding and when did you use this source?

	Before flooding	During flooding	After flooding	All the time	Never
Daily TV news	○	○	○	○	○
Newspaper	○	○	○	○	○
Online news/news app	○	○	○	○	○
Weather app	○	○	○	○	○
Warning app (e.g., NINA)	○	○	○	○	○
Social media (e.g., Twitter)	○	○	○	○	○
Friends & Family	○	○	○	○	○
Neighbours	○	○	○	○	○
Local government	○	○	○	○	○
Sirens	○	○	○	○	○
Other	○	○	○	○	○

What you expected and what really happened

11. How likely did you think that flooding would happen when you heard about it for the first time?

- ○ Very likely
- ○ Somewhat likely
- ○ Somewhat unlikely
- ○ Very unlikely

12. Did you imagine that you would be affected by flooding when you first heard about it?

- ○ Yes
- ○ No
- ○ Eventually

13. How serious did you imagine the flooding would be when you first heard about it?

	Serious flooding	More flooding than usual	Usual flooding	Minor flooding	No flooding
What you imagined	○	○	○	○	○
What was the reality	○	○	○	○	○

14. How did the following information affect your actions/behaviour/preparedness?

	It did not worry me	It did not have any effect on my actions before and during the flood	It made me unsettled/ frightened	I started with preparations	I did not receive this information
The expected amount of rainfall	○	○	○	○	○
That river water levels might exceed their banks	○	○	○	○	○
Warning for flooding	○	○	○	○	○
Information on potential impact of the rain	○	○	○	○	○
Information on potential impact of the flood	○	○	○	○	○
Suggested actions for you	○	○	○	○	○
That flooding is likely but not certain	○	○	○	○	○
Fake news - incorrect news	○	○	○	○	○

What would you do different in the future?

15. Imagine you would receive a flood warning now: what would you do different to when you received information on the potential flooding in July?

16. Imagine you would receive a flood warning now: which sources would you trust/rely on? (You may select more than one option) *

- [ ] Daily TV news
- [ ] Newspaper
- [ ] Online news/news app
- [ ] Weather app
- [ ] Warning app (e.g., NINA)
- [ ] Social media (e.g., Twitter)
- [ ] Friends & Family
- [ ] Neighbours
- [ ] Local government
- [ ] Sirens
- [ ] Other

17. Were you aware of areas that are at risk of flooding in your neighbourhood before July 2021? *

- ( ) Yes
- ( ) No
- ( ) Not of all

Your opinion on the flood event

18. How could communication of potential flooding be improved? *

19. What actions can you take yourself to be better prepared for future flooding? *

20. In your opinion, which issues arose during the flooding in July 2021?

21. How could these issues be prevented?

22. What do you expect from your local/regional/national government before/during/after disasters like flooding?

23. Would you like to be more involved in *

- [ ] actions for flood risk reduction
- [ ] decisions on climate change (incl. flooding and other natural hazards)
- [ ] disaster management (e.g., response to flooding)
- [ ] warning dissemination
- [ ] awareness raising on potential future risks
- [ ] I don't want to be involved in anything
- [ ] Other

Final Questions

24. Please, enter your postcode *

25. Please, select your age group *

- 18-24 years
- 25-54 years
- 55-64 years
- 65 and above
- Prefer not to say

26. Where do you live? *

- In my own house
- In my own flat
- In a rented flat
- In a rented house
- I live with my parents/others
- Prefer not to say
- Other

Thank you for your participation!

If you have any questions, comments, or similar you can contact Joy Ommer via email j.ommer@pgr.reading.ac.uk

Appendix 3: Supplementary Material: No-regrets actions

This appendix presents the Supplementary Material of Chapter 7.

Supplementary Material

Action	Level of uncertainty and preparedness timing				Individual/ Collective	Robust/ flexible	Costs-effective	Benefits	Likely co-benefits	Easy-to-implement	Probable regret level	References
	Unknown future	**Plausible future scenarios**	**Probable alternatives**	**Clear (enough) future**	*I= Individual C= Collective*	*R= Robust F=Flexible*	*Cost: no, low, medium, high Efficacy: low, medium high*	*List*	*List*	*E= easy M=medium D=difficult*	*No-regret Low-regret*	
	Anytime (unaware of risk)	Anytime (aware of local risks)	Forecast indicating probable threat (days-weeks)	Hazard warning issued (hours-days)								
Familiarise yourself with local risk areas – is your home in a risk area?					I&C	R&F	Costs: no	Awareness & knowledge	Co-benefits: motivation for flood preparedness; disbenefit: potential anxiety	E	No-regret	[1]
Future visioning and hazard imagination workshop					C	R&F	Costs: no	Awareness & knowledge	Co-benefits: enhanced self-efficacy, collective agency, challenge anticipation, long-term vision; disbenefit: potential anxiety	E-M	No-regret	[2,3]
Developing a household and/or neighbourhood emergency plan					I&C	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[1]
Evacuation (when to evacuate; where to go to; which route to take; where are shelters)					I&C	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[4–6]
Practice household emergency plan					I&C	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[1]
Learn how the local or national early warning systems works; co-develop a system if it is not available a community level					I&C	R&F	Cost: no *Costs may apply if a community early warning system does not exist	Awareness & knowledge; Coping capacity	Peace of mind	E-D	No-regret	[7]

Learn about and clarify roles and responsibilities in disaster context					I&C	R&F	Costs: no	Awareness & knowledge	Self-responsibility; empowerment; social cohesion	E-M		[8]
Be attentive to weather warnings and updates					I	R&F	Cost: no	Awareness & knowledge	Gaining an understanding of local weather patterns and thresholds	E	No-regret	[9]
Lobby against urban developments that will increase runoff onto one's property					I&C	R&F	Cost: no-low	Awareness & knowledge; Flood mitigation	Raising awareness within the community and authorities	E-M	No-regret	[10]
Communicate interventions within community including vulnerable neighbours; make sure information is understandable by as many people as possible by including indigenous community members					I&C	R&F	Cost: no	Awareness & knowledge	Peace of mind; anticipation guilt of not having helped; increase self-responsibility	E	No-regret	[4,11]
Start a conversation about how an emergency might affect your local community					C	R&F	Costs: no	Awareness & knowledge	Peace of mind; increasing social capital	E	No-regret	[12]
Identify climate champions in your community					C	R&F	Cost: no-low	Awareness & knowledge	Motivation for action taking	E	No-regret	[13]
Establish climate schools (e.g., for farmers, young generation)					I&C	R&F	Costs: no-medium	Awareness & knowledge	Motivation for action taking; self-responsibility; empowerment	E-M	No-regret	[14]
Develop a climate youth club					I&C	R&F	Cost: no-low	Awareness & knowledge	Motivation for action taking; self-responsibility; empowerment	E-M	No-regret	[6]

Restore wetlands					C	R&F	Costs: low-high Efficacy: medium-high	Flood mitigation	Increasing biodiversity; community cohesion; re-creational area	M-D	No-regret	[15,16]
Increase local water retention capacity by planting trees and local species					C	R&F	Costs: low-high Efficacy: medium-high	Flood mitigation	Peace of mind; increasing biodiversity; community cohesionwell-being	M-D	No-regret	[17–19]
Increase local water storage capacity with e.g., detention and retention ponds; rechannelling streams; etc.					C	R&F	Costs: low-high Efficacy: medium-high	Flood mitigation	Peace of mind; increasing biodiversity; community cohesionwell-being	M-D	No-regret	[15,17–19]
Removal of debris, litter, foliage or similar from river sides; dredging riverbed					I&C	R&F	Cost: no-low	Flood mitigation	Peace of mind; social cohesion; well-being	E-M	No-regret	[9,19,20] [4]
Start monitoring rainfall amounts, water depths, etc. with low-cost sensors and establish your own local thresholds					I&C	R&F	Cost: no-low	Awareness & knowledge	Peace of mind; gaining an understanding of local weather patterns and thresholds	E	No-regret	[1,21]
Create monitoring networks					C	R&F	Cost: no-low	Awareness & knowledge	Social connectedness; common understanding of local weather patterns and thresholds	M	No-regret	[15]
Observe the environment for changes					I&C	R&F	Cost: no	Awareness & knowledge	Gaining an understanding of local changes	E	No-regret	[6]
Organise psychoeducation to community members on stress					I&C	R&F	Costs: no-medium	Coping capacity	Peace of mind; better understanding on one's own	E	No-regret	[11]

reactions and coping to reduce distress and promote adaptive functioning									behaviour and emotions			
Create a self-care plan in advance of a disaster or emergency. Anticipating, monitoring and understanding your own and your loved ones' reactions will really help during an emergency					I	R&F	Costs: no	Coping capacity	Peace of mind; increasing psychological strengths	E	No-regret	[12]
What are the things in your life that cannot be replaced, and that have great meaning for you or your loved ones? Think about ways you can protect these things in an emergency					I	R&F	Costs: no	Coping capacity	Peace of mind	E	No-regret	[12]
Diversify household incomes					I&C	R&F	Costs: no-high Efficacy: medium-high	Reducing economic vulnerability	Peace of mind	M-D	Low-regret	[4,18,22]
Learn about government schemes (e.g., for agriculture and farming practices)					I	R&F	Costs: no	Reducing economic vulnerability; Flood mitigation	Learning/adopting new practices; reduced costs; increased revenue	E	No-regret	[4]
Adopt flood resistant/ climate resilient agricultural practices					I	R&F	Costs: no-high Efficacy: low-high	Reducing economic vulnerability	Peace of mind; knowledge on new practices	E-D	Low-regret	[4]
Preparing for power outages by developing and off-grid energy supply,					I&C	R&F	Costs: no-medium	Coping capacity	Peace of mind	E	No-regret	[4]

having battery back-ups												
Store food and other items of basic need in a safer place; increase stilted food storages					I	R&F	Cost: no-low	Coping capacity	Peace of mind	E	No-regret	[4]
Keep drains clear					I	R&F	Cost: no Efficacy: low-medium	Flood mitigation; damage mitigation	Peace of mind; physical exercise	E-M	No-regret	[23]
Increasing property water retention capacity (e.g., remove paving in the garden; plant local species; green roofs; rain gardens; tree planting and protection; bioretention cells; vegetated swales)					I	R&F	Costs: low-high Efficacy: low-high	Flood mitigation	Aesthetics; promoting biodiversity; improving air quality	E-M	No-regret	[4,17,24–26]
Increasing property water storage capacity (e.g., tanks; retention pond) and harvest rainwater					I	R&F	Costs: low-high Efficacy: low-high	Flood mitigation	Water storage for watering plants during dry periods; biodiversity	M-D	No-regret	[5,26]
Act as a flood warden					I	R&F	Cost: no	Awareness & knowledge; Coping capacity	Increasing self-responsibility; empowerment; improving communication between citizens and authorities	M-D	No-regret	[9]
Join or found a flood action group					I&C	R&F	Cost: no	Awareness & knowledge; Coping capacity	Increasing self-responsibility; empowerment; improving communication	E	No-regret	[9]

									between citizens and authorities			
Develop hazard and vulnerability maps based on local knowledge; extend already existing hazard maps with local knowledge					C	R&F	Cost: no-low	Awareness & knowledge; Coping capacity	Increasing social capital and social cohesion	E-M	No-regret	[15]
Engage in the planning and implementation of local strategies and actions for flood mitigation					I&C	R&F	Cost: no	Awareness & knowledge; Flood mitigation	Peace of mind; anticipation guilt of not having helped; increase self-responsibility; increasing self-responsibility	E-M	No-regret	[4,6,9,27,28]
Be politically active to guide the community towards flood preparedness					I&C	R&F	Cost: no	Awareness & knowledge; Coping capacity	Peace of mind; increasing self-responsibility; empowerment	E-M	No-regret	[9]
Create a joined neighbourhood flood network; mutual help associations					C	R&F	Cost: no	Awareness & knowledge; Coping capacity	Peace of mind; increasing social capital and cohesion	E-M	No-regret	[18,29]
Develop a community emergency plan including evacuation meeting points					C	R&F	Cost: no	Awareness & knowledge; Coping capacity	Peace of mind; increasing social capital and cohesion	E-M	No-regret	[27,30]
Set up joint flood stores with tools and materials for emergency cases					C	R&F	Costs: no-medium	Coping capacity	Peace of mind	E-M	No-regret	[9]
Conduct joint flood drills with neighbours					C	R&F	Cost: no	Awareness & knowledge; Coping capacity	Peace of mind; increasing social capital and cohesion	E-M	No-regret	[9]
Educate younger generations on					I&C	R&F	Cost: no-low	Awareness & knowledge;	Peace of mind; preservation of traditions	E-M	No-regret	[31]

traditional flood protection methods								Coping capacity				
Move to a no-risk area					I	R	Cost: high Efficacy: high	Reducing economic vulnerability	Peace of mind	D	Low -regret	[9,32]
Obtain or renew a property insurance (for flooding)					I	R&F	Costs: medium-high Efficacy: medium-high	Reducing economic vulnerability	Peace of mind	E	Low-regret	[5,25,27,29, 33]
Encourage your neighbour to purchase an insurance (for flooding)					I&C	R&F	Costs: no	Reducing economic vulnerability	Good neighbourhood relations; Peace of mind	E-M	No-regret	[27]
Try to influence the property owner/housing cooperative to take preparedness measures					I&C	R&F	Cost: no	Damage mitigation	Peace of mind	E-M	No-regret	[10]
Building a house in a flood risk area, consider elevating the ground floor, floating options, stilts, water insensitive materials, suitable positioning of utility networks (e.g., electricity, drinking water, sewage), placing a tub around the basement, etc.					I	R	Costs: high Efficacy: high	Damage mitigation	Peace of mind	M-D	Low-regret	[15,27,34]
Installation of backflow preventers					I	R	Costs: low-high Efficacy: medium	Damage mitigation	Peace of mind	M-D	Low-regret	[9,32]
Adapting the building use and interior fitting					I	R&F	Costs: no-high	Damage mitigation	Peace of mind	E-M	No-regret	[29,32,35]

							Efficacy: medium					
Buying, maintaining pumps, and learning how to use them					I	R&F	Cost: low	Coping capacity	Peace of mind	E	No-regret	[9,10]
Buying sandbags and placing them easily accessible					I&C	R&F	Cost: low	Coping capacity	Peace of mind	E	No-regret	[9,10]
Buying and installing stationary or mobile flood barriers					I	R	Costs: medium-high Efficacy: medium-high	Coping capacity; Damage mitigation	Peace of mind; potential price reduction for flood insurance	E-M	Low-regret	[4,5,10,27,29,32]
Knowing where to park the car in an emergency					I	R&F	Cost: no	Coping Capacity	Peace of mind	E	No-regret	[23,29]
Communicate dangerous behaviour including going into flooded basements; walking or driving in flood water					I&C	R&F	Cost: no	Awareness & education	Peace of mind	E	No-regret	[1]
Talk to your neighbour about flood preparedness and mitigation					I	R&F	Cost: no	Awareness & knowledge	Peace of mind; good neighbourhood relations	E	No-regret	[27]
Knowing your neighbours and who might need support in case of an evacuation or in long and short-term preparedness					I&C	R&F	Cost: no	Awareness & knowledge	Peace of mind	E	No-regret	[9,10,27]
Redirect water flow around the house					I	R&F	Cost: no-low	Damage mitigation	Peace of mind	E-M	No-regret	[36]
Keep feed for livestock in a waterproof place					I	R&F	Cost: no-low	Coping capacity	Peace of mind	E	No-regret	[24,37]

Knowing where to evacuate livestock to					I	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[24,38]
Seek guarantees that the area will get special attention from rescue authorities in case of a new emergency					I&C	R&F	Cost: no	Reducing vulnerability	Peace of mind; increasing awareness	E-M	No-regret	[10]
Moving valuable items, documents, etc. upstairs					I	R&F	Cost: no	Damage mitigation	Peace of mind	M	No-regret	[9,29,35]
Organising temporary accommodation or knowing where shelters are					I&C	R&F	Costs: no-medium Efficacy: high	Coping capacity	Peace of mind	E	No-regret	[1,4,9]
Preparing an emergency kit including important documents, medicines, clothes, water, and food, etc.)					I	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[4,6]
Having medicines for pet and livestock prepared					I	R&F	Cost: no	Coping capacity	Peace of mind	E	No-regret	[24]
Keep ropes to make boats from banana tree					I&C	R&F	Cost: no-low	Coping capacity	Peace of mind	E	No-regret	[4]
Communicate flood warnings within the community (e.g., via social media); avoid the spreading of fake news					I&C	R&F	Cost: no	Awareness & knowledge	Peace of mind; prevention of guilt	E	No-regret	[10,23]
Switch off gas, electricity, etc.; protect oil tanks; sealing air conditioning or ventilation systems;					I	R&F	Cost: no	Damage mitigation	Peace of mind	E	No-regret	[29,32]

securing dangerous substances												
Waterproof your home by installing owned flood barriers, pumps, or placing sandbags around the house					I	R&F	Costs: no	Damage mitigation	Peace of mind	E-M	No-regret	[4,5,10,27,29,32]
Reparking the car					I	R&F	Cost: no	Damage mitigation	Peace of mind	E	No-regret	[1]

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Appendix 4: Submitted Article: The impact of spatial resolutions on Nature-based Solution suitability mapping for Europe

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Article

The Impact of Spatial Resolutions on Nature-Based Solution Suitability Mapping for Europe

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Featured Application: Results provide essential information for the initial design and adaptation potential of Nature-Based Solutions. It may serve as guidance to practitioners and data providers.

Abstract: Flooding events, like in Germany in 2021, highlight the need for re-naturalising banks of rivers and streams to naturally mitigate future flooding. To identify potential areas for Nature-Based Solutions (NBS), the NBS Toolkit—a decision-support tool for Europe—was developed within the H2020 OPERANDUM project. The tool builds on suitability mapping, which is progressively adopted for pre-assessing areas for Nature-Based Solutions. The NBS Toolkit operates with European open-source data, which is available at different spatial resolutions. In this study, we performed a GIS-based analysis to examine the impact of different resolution data on the resulting suitability maps. The results suggest that for large-scale measures such as riparian forest buffers, coarser resolutions are sufficient and may save processing time and capacities. However, fine resolution datasets can bring added value to urban suitability mapping and are of greater importance for small-scale, local Nature-Based Solutions.

Keywords: natural flood management; land use and land cover; GIS; flood risk reduction

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1. Introduction

Nature-Based Solutions (NBS) have been gaining a significant role in disaster risk reduction, climate change mitigation and adaptation, as well as in sustainable development [1]. Their rising importance in policies and practice in Europe can be ascribed to their character as natural measures which simultaneously offer co-benefits for the socio-ecological system [2,3].

The increasing recognition of NBS in Europe is linked to the ambition to implement them at various scales in rural and urban areas [4]. To enhance the uptake of NBS, it is necessary to support the decision-making of policy makers, practitioners, associations, and further actors who are not experts in this field but are engaged in the planning and implementation of NBS because they have specific requirements (e.g., for soil) that need to be considered. Hence, to determine the suitability of a particular NBS for an area of interest, several criteria need to be fulfilled. For decision-support, a preliminary assessment can be conducted based on local characteristics (e.g., soil, land cover, vegetation, and built-up areas) to gain an initial understanding of the suitability of an NBS. This type of multi-criteria pre-assessment in NBS is referred to as suitability mapping [5], (site) suitability analysis/assessment [6], or, alternatively, as opportunity mapping [7]. When conducting a

complete suitability analysis for real-world application, several additional criteria which are not covered in the pre-assessment may also need to be considered. These additional criteria may be social aspects (e.g., acceptance of the NBS by the public), legal factors (e.g., land ownership, policies in context of the permission of NBS), and the economic component (e.g., funding for the land reimbursement, implementation, and maintenance) [5,8–11].

Existing suitability mapping tools and studies vary in their scale, although the following core approach remains similar: focus on urban areas and city scale [11], perform subnational scale analysis primarily for rural areas [12], map NBS suitability at a larger scale (e.g., national) [5], and at a global scale [7]. However, NBS suitability mapping has not been approached at the European level yet. In response to this gap and the increasing promotion of NBS in Europe, as well as the complexity of decision-making for NBS, we developed the NBS Toolkit [13] (within the H2020 OPERANDUM project) to support decision-making for NBS in rural and urban areas. The NBS Toolkit aims to recommend NBS locations for the entire European region at the local scale. The suitability mapping of the toolkit builds on open-source data at the European scale, but the available datasets can vary greatly in resolution. For instance, datasets for land use and land cover (LULC) are available in 100 m, 50 m, and down to 2 m resolution. In order to gain evidence on the appropriateness of these different open-source datasets for the suitability mapping at the regional scale, this study aims to assess the influence of different spatial resolutions on the resulting suitability maps.

Differences in spatial resolution can be further related to differences in accuracy and data size, and have been found to impact the computation outcome, i.e., in the context of hydrological modelling [14–18], ecosystem service assessments [19,20], or agricultural suitability mapping [21]. These studies discussed the result accuracy, the adequateness of fine resolution in the context of the desired goal of a study, and the feasibility of fine resolution, considering computation capacity. In terms of accuracy of the results, it was found that accuracy increases equally with finer spatial resolution [19], provided that all input layers are of a similar resolution [15]. Considering the desired output scale, fine spatial resolution could be a precondition, i.e., for urban suitability mapping due to greater land use heterogeneity [19]. Hence, which output scale is desired should be considered [18]. Other selection factors for input layers are the availability of data, the computation resources (e.g., processing time and capacity), and data storage [15,19,21]. In this context, the results of this study shall indicate whether the usage of fine resolution layers is non-neglectable for NBS suitability mapping for the NBS Toolkit. Based on the existing literature in other research fields, we hypothesise that for urban areas, fine resolution input datasets are required, while for rural areas, coarser resolutions may be acceptable.

To test this hypothesis, firstly, we introduce the test study area and NBS and its suitability criteria (Section 2). Secondly, we identify open-source European datasets to represent the suitability criteria (Section 3.1), and describe the methods used for the suitability mapping (Section 3.2), as well as analysis and validation of the results (Section 3.3). Section 4 will present the results, which will be discussed in Section 5, and concluded in Section 6.

2. Study Area and NBS

The NBS Toolkit aims to recommend Nature-Based Solutions at the local scale across Europe and, therefore, is based on open-source input layers at the European scale. Yet, it is aimed to derive local recommendations, which can be of different sizes. In order to gain a better understanding on the appropriateness of three different LULC datasets for this purpose, the testing is performed in the following selected test area: the federal state Rhineland Palatinate in Germany (Figure 1). This area was selected due to its rural and urban land uses, as well as the recent flooding event in July 2021. The results of this test site are then used to compute the suitability maps at the European scale.

The test study area (Rhineland Palatinate) encompasses 19,846 km^2 and is located in the west of Germany, where the riverbanks of the rivers Rhine, Moselle, and Ahr are primarily covered by wine yards, roads, and small urban areas; thus, riverbanks are largely occupied by agricultural and built infrastructure. The area was severely affected by flooding

in 2021. The event highlighted the challenges of the densely built river sides, which were largely flooded; hence, recovery actions have also been striving to enhance the water retention and storage capacities [22–24].

With the focus of the test study area on flooding, one solution for future flood reduction is to make room for the river in the upstream of built-up areas. For the test study, riparian forest buffers were selected due to their ability to slow water runoff with their rooting system, filter sediments through greater friction, and increase infiltration and storage of water by enhancing soil conditions [25–27]. Hence, slowing runoff and enlarging water storage areas along German streams and rivers can help to compensate densely built-up riverbanks. Yet, the effectiveness of riparian buffers for flood reduction is dependent on the width and length of them; thus, their planting should be targeted to extend existing buffer habitats to counteract habitat fragmentation [28,29].

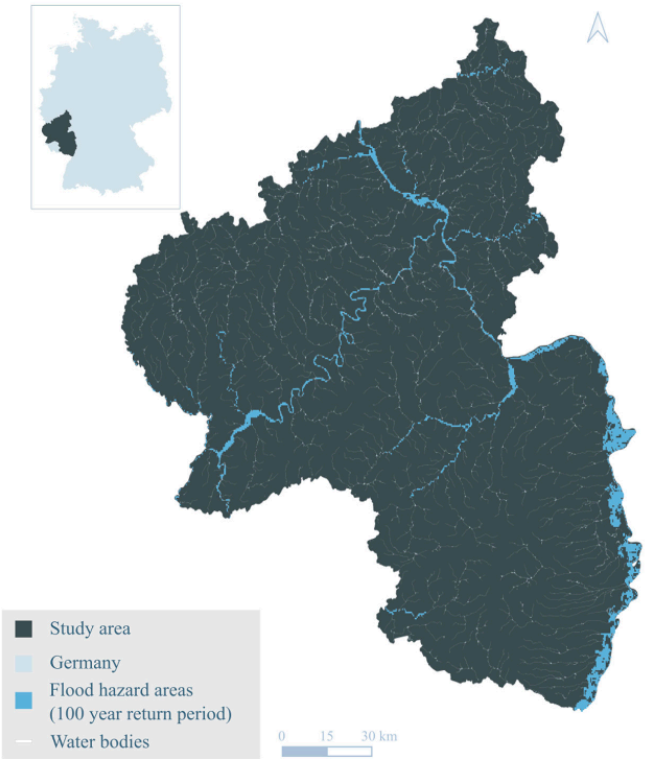

Figure 1. The test study area, Rhineland Palatinate in Germany, depicted with the water bodies [30] and flood hazard areas [31].

Riparian Forest Buffer Suitability Criteria. The following suitability criteria for riparian forest buffer zones were identified from the literature:

- *Land use and land cover.* Riparian forest buffers are commonly implemented on agricultural and pastural land, but also on unvegetated areas, which are often associated with low infiltration rates and high runoff potential compared to forest areas [32,33]. In accordance, the following land use and land covers can be defined as suitable: agricultural areas, pastures, natural grassland, sparsely vegetated areas, and burnt

areas. Furthermore, forests with low cover density can be suitable for riparian forest buffer restoration (discussed in the next sub-section: forest density). Land cover types such as dense urban areas and water bodies were deemed not suitable.

- *Forest density.* Forests can intercept and store water in a manner comparable to sponges, and on average, forest covers with densities of 30% or more are found to have higher water retention abilities. Yet, this retention potential threshold is varying between forest types (e.g., coniferous forests have higher runoff retention potentials), biogeographical zones (e.g., alpine, boreal, continental), and seasons [34]. Rhineland Palatinate is located in the continental region; thus, according to the EEA [34], the threshold for a medium retention potential of broad-leaved tree cover density threshold is 20%, while for coniferous and mixed forests it is even lower. High retention potential thresholds are above 65% for coniferous forests and 80% or more for broad-leaved forests.
- *Soil.* Different aspects of soil can be favourable or limiting for planting trees. Firstly, a soil depth at a minimum of 0.6 m and a mean depth of 3.2 m allow trees to grow roots [35], whilst a bulk density greater than 1.6 g/cm is restricting to root growth [36]. Regarding the water retention potential, soil textures such as silts and loams have an efficient water intake and water holding rate [37].
- *Built-up areas.* Limiting factors for the planting of riparian forest buffers are existing buildings, whether industrial, public, or private houses. In addition, transport infrastructures such as railways or roads may be excluded. Transportation ways are further causing fragmentations of habitats since they function as barriers for wildlife.
- *Water.* Riparian forest buffers are treed corridors along water bodies. The recommended width of a buffer is dependent on the purpose (e.g., flood reduction, bank stabilisation, biodiversity enhancement) and the size of a flowing water body (e.g., streams and rivers). Buffer widths are recommended to start at 12 m, but for supporting biodiversity, buffers should be at least 30 m wide. For water bodies with a width of 2 m or less, a buffer could already be starting at 5 m [25,26,28,38].

In this study, suitable areas for riparian forest buffer zones are mapped for flood risk reduction. For this purpose, it could be argued that flood risk areas should be added as a suitability criterion. However, we did not include this criterion in this analysis because, firstly, riparian buffers can be implemented in upstream areas to reduce the flood risk downstream [39], and secondly, at the European scale, the flood hazard maps [31] do not include smaller streams and ditches; thus, the dataset was not considered to be completely suitable for this analysis.

3. Materials and Methods

For the aim of gaining clarity on the impact of spatial resolution on the suitability mapping of NBS, we used a GIS-based approach (Figure 2) for the test study area and NBS. The results of this test study shall inform the wider application of the suitability mapping for the European-focused NBS Toolkit.

The GIS-based approach of this study included, firstly, the selection of open-source input layers at the European scale (Section 3.1), and secondly, the multi-criteria suitability mapping utilising the selected raster and vector input layers (Section 3.2). The suitability mapping was performed by applying the Boolean multi-criteria analysis [40] to three different LULC input layers (CORINE Land Cover, LUISA base map, and OpenStreetMap), which differ in their spatial resolution. The suitability mapping resulted in three outputs (one for each LULC input layer). To gain a better understanding of the impact of the three different spatial resolution layers on the output suitability maps, the following analysis and validation methods were used in the final step (Section 3.3): patch and landscape statistics, cohesion analysis, and satellite validation.

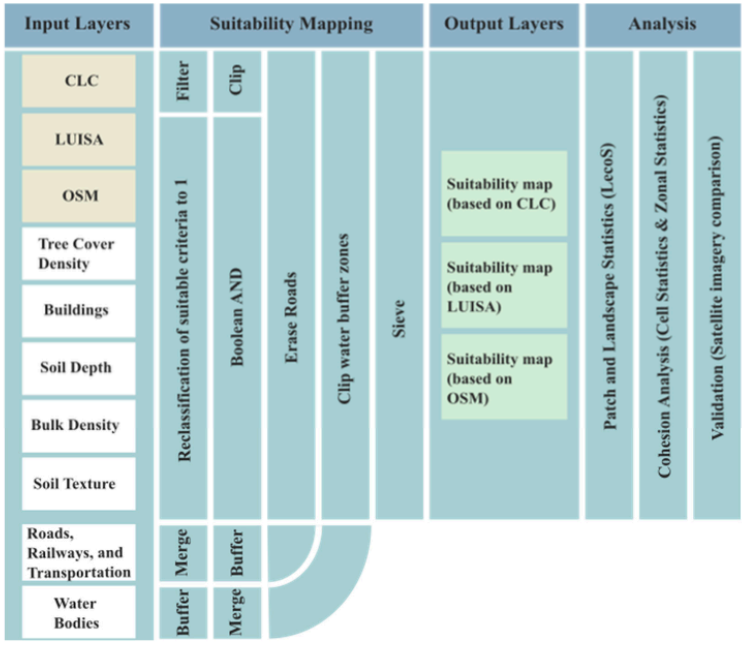

Figure 2. The GIS-based workflow of this test study.

3.1. Input Layers

At the European scale, the following three possible LULC input layers (which provide a sufficient classification of land cover types) were identified with differing spatial resolutions:

- CORINE Land Cover (CLC) [41], published in 2018, presents a visual interpretation of high-resolution satellite imagery from 2017 and 2018. The raster layer has a spatial resolution of a minimum of 100 m, a data storage size of 206.2 MB, and contains 44 LULC classes.
- LUISA base map (2018) [42] builds on the CLC layer (2018), COPERNICUS high-resolution (10 m) layers from 2018, the COPERNICUS Urban Atlas (2018), the Global Human Settlement Layer (2015), the TomTom Multinet vector layer, and OpenStreetMap data (2020). The LUISA base map is a raster layer with a minimum spatial resolution of 50 m and a data storage size of 1.02 GB.
- OpenStreetMap (OSM) [43] is a crowdsourced vector layer produced and updated by volunteers digitising satellite imagery, and it is validated with aerial imagery, GPS devices, and low-tech field maps. The dataset has an accuracy of at best 2 m, and a data storage size of 26 GB for Europe in 2022.

For the other identified suitability criteria in (Section 2), representative open-source datasets at the European scale were selected for the suitability mapping. The representative datasets, along with the related suitability criteria, their spatial resolution, temporal range, and source, are listed in Table 1.

Resampling and reprojection. As all selected layers differ in their spatial resolution (see Table 1) and the suitability mapping works on cell level, the input layers were resampled to one common spatial resolution of 10 m. Discrete layers (soil texture and buildings) were resampled by applying the nearest neighbour method; whereas, layers with more continuous information (tree cover density, soil depth, and bulk density) were resampled using the cubic method. In addition, all layers were reprojected to the following com-

mon coordinate reference system: the ETRS89 Lambert Azimuthal Equal-Area projection coordinate reference system (EPSG:3035).

Table 1. Input layers for the suitability mapping of riparian forest buffers.

Layer	Suitable Criteria	Spatial Resolution	Temporal Range	Source
LULC: Corine Land Cover (CLC)	Agriculture, pastures, natural grassland, sparsely vegetated areas, burnt areas, and (broad-leaved) forests	100 m	2017–2018	[41]
LULC: LUISA Base Map (2018)		50 m	2017–2018	[42]
LULC: OpenStreetMap (OSM)		n/a	2022	[43]
Tree Cover Density 2018	0–20% forest density retention threshold (for continental climate)	10 m	2018	[44]
Buildings (European Settlement Map (ESM))	Areas without buildings	10 m	2015	[45]
Roads, Railways, Transport	With a 3 m buffer	n/a	2022	[43]
Soil Depth	>60 cm	250 m	1950–2015	[46]
Bulk Density	<1.6 g/cm	500 m	2009	[47]
Soil Texture (USDA)	soils with efficient water intake: sandy loam, loamy sand, sandy clay loam, loam, silty loam silt loam, and clay loam	500 m	2009	[47]
EU-Hydro	Buffers around water areas: Canals/Ditches = 5 m Rivers (line) = 15 m River (polygon) = 30 m	1 ha	2006–2012	[30]

3.2. Suitability Mapping Based on Multi-Criteria Analysis

The method of multi-criteria analysis (MCA) offers the possibility to integrate a larger number of criteria that need to be considered for assessing the suitability of an area. As introduced above, NBS are selected based on different suitability criteria. MCA enables the integration of all criteria. Similar to the method used by other NBS decision tools [5,7,11,12], for the MCA suitability mapping, the layers for each criterion are overlaid to identify areas where all criteria are met. GIS-based MCA methods offer three ways for overlaying layers [40], as follows: (1) Boolean; (2) weighted; or (3) fuzzy memberships. For this study, the Boolean method was chosen to be most suitable, and was used in this study.

Creation Boolean layers. For the MCA, all input layers were transformed into Boolean layers. In particular, the CLC and LUISA land cover layers, as well as additional raster layers (soil depth, bulk density, soil texture, tree cover density, and buildings), were reclassified (according to the criteria outlined in Table 1) to a binary scale with values of 0 and 1, of which the value of 1 indicates suitable areas. For the OSM vector layer, suitable land covers were filtered and extracted. Intermediate results are presented as follows in Figure 3, which displays the suitable areas indicated by the three LULC layers: Figure 3a (LUISA), Figure 3b (OSM), and Figure 3c (CLC).

Boolean multi-criteria analysis. The first part of the MCA was performed with the Boolean AND tool. This intermediate output layer (Figure 3d) shows all suitable areas where all criteria are met (except LULC layers). Following this step, the intermediate layer was overlayed with each of the three binary LULC layers. To include vector layers in the Boolean MCA, a different approach was adopted, since the Boolean AND is a raster tool. Hence, the filtered OSM layer was used to extract suitable areas. After this process, three output suitability maps were available, one for each of the three LULC layers. To further exclude transport lines, the OSM line vector layers of roads, railways, and transport were merged and buffered with 3 m. With this resulting layer, suitable areas located on these transportation lines could be removed with the erase tool. Similarly, the EU-Hydro layers

were merged and buffered with different buffer widths depending on the type of waterway (see Table 1). Finally, suitable areas within the water buffer could be extracted.

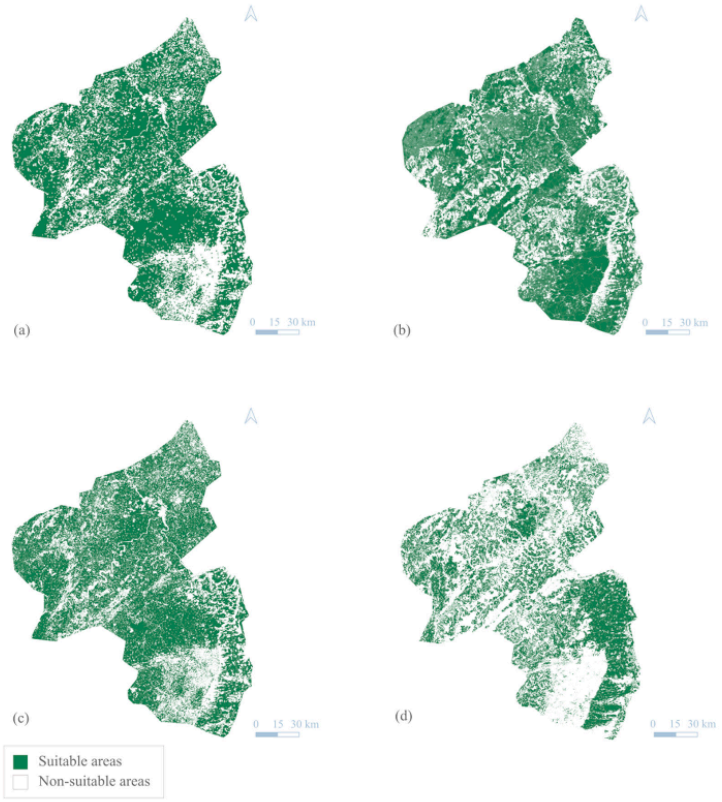

Figure 3. This figure presents the Boolean output layers for the study state of Rhineland Palatinate in Germany; (**a**–**c**) present each of the three LULC layers after the reclassification to Boolean layers: (**a**) LUISA base map, (**b**) OSM, (**c**) CLC; and (**d**) presents the suitable areas where all criteria (except LULC) are indicating suitability.

Exclusion of fragmented areas. The three resulting output layers show suitable areas along rivers, streams, ditches, and canals. However, these areas were found to be highly fragmented, considering that riparian forest buffers are more effective when they are, firstly, connected to existing forest habitats, and secondly, when they have minimum lengths and widths. Therefore, the three outputs were further processed to exclude small areas. This exclusion of areas less than 100 aligned cells (with a 10 m resolution) was performed with the GDAL sieve tool, and the final suitability maps were produced.

3.3. Analysis and Validation

The suitability mapping resulted in three different outputs. Based on these, further analysis and validation was performed to gain a better understanding on the suitability of each LULC layer for the integration into Europe-wide suitability mapping for the NBS Toolkit. For this purpose, the three output suitability layers were quantitatively analysed with cell and patch statistics, and qualitatively validated with satellite imagery.

Cell statistics. QGIS raster cells statistics were applied to assess the coherence of the three output layers. Comparing these layers on a cell-basis indicates whether the outputs suggest the same suitable areas or not. In particular, a new layer was created in which each cell has a value ranging from 0–3:3, indicating high coherence—meaning that all three suitability mapping outputs suggest suitability; a value of 2 presents areas where two layers (out of the three) indicate suitability, 1 suitability is suggested with one layer only, and those with a value of 0 are non-suitable areas.

Patch statistics. Statistical analysis, or so-called patch statistics, was used to derive information on the suggested riparian forest buffer sizes and the degree of fragmentation. Patch statistics were performed using the QGIS plugin LecoS 3.0 [48]. This plugin is based on the FRAGSTATS (v4) software [49] commonly used in landscape ecology for patch and landscape analysis. The following metrices were calculated: (1) land cover, to calculate the entire area for potential riparian forest buffers; (2) number of patches, to present the difference in the number of suggested areas; (3) patch density (land cover divided by number of patches), which indicates how dense the suggested riparian forests are to each other; (4) maximum and mean riparian area sizes; and (5) the landscape division index, to analyse the degree of fragmentation of the suggested riparian forest areas with values ranging between 0 and 1, while 1 indicates patchiness, and hence, fragmentation.

Satellite image validation. Qualitative assessment was used to validate the (thematic) accuracy and appropriateness of the suggested riparian areas. At this point, we define thematic accuracy as the correctness degree of the suggested areas; for instance, considering a LULC layer of 100 m, the resolution cannot present LULC class borders as accurate as in reality, whilst the appropriateness is considered as the actual suitability of a suggested area. For this qualitative validation, the Google satellite images layer (2022) was overlayed with each of the three output maps to assess whether suggested areas are thematically accurate and appropriate. For instance, whether suitable areas are placed inside water areas (due to a lack of accuracy) or on camping sites (which may not be appropriate).

4. Results

The suitability mapping resulted in three different suitability maps (one for each LULC input layer), indicating areas suitable for implementing riparian forest buffer zones. These three suitability maps were further analysed with (1) cell statistics to compare the suggested suitable areas in terms of coherence with another; (2) patch statistics to assess the degree of fragmentation of proposed suitable areas; and (3) satellite image validation to qualitatively assess the accuracy and appropriateness of the suggested areas. The results of these analyses are presented in the following section.

Suitable area size comparison. Overall, the three maps differ in the total size of suitable area and their structure (e.g., number of suitable areas; maximum and mean size). The total size of suitable areas (Table 2) for the LUISA- and CLC-based output maps is around 25,000,000 m^2, while the OSM-based suitability map differs greatly by counting only 14,381,000 m^2. According to the results listed in Table 2, the largest and the mean suggested areas (patches) are of a similar size between all output layers. Interestingly, the sizes of the largest patch and of the mean patch area are higher before removing (sieving) small areas.

Suitable area coherence. Comparing the actual suggested areas by overlaying these three output layers and using cell statistics (Figure 4), only 56.8% of the suggested areas are found to be coherent between all three layers, 31.6% by two layers, and 10.6% by single layers. Hence, the results show that the output maps greatly differ from one another, while the difference of 11.2% between the outputs of the CLC and LUISA layers is much lower than that of the OSM layer. This result can be explained by the fact that the LUISA layer is based on the CLC layer.

Table 2. Patch statistics of the suitability mapping output layers for each LULC input layer before and after removing isolated small areas (sieving).

Metric	OSM	OSM (Sieved)	LUISA	LUISA (Sieved)	CLC	CLC (Sieved)
Land Cover (m^2)	36,825,700	14,381,000	54,319,900	24,027,300	57,086,100	25,345,300
Number of Patches	14,750	720	14,699	1196	15,464	1244
Greatest Patch Area (m^2)	168,900	136,400	145,500	130,500	173,400	130,500
Mean Patch Area (m^2)	2496.65	19,973.61	3695.48	20,089.72	3691.55	20,374.04
Patch Density	0.00040054	0.00005007	0.0002706	0.00004978	0.00027089	0.00004908
Landscape Division Index (dimensionless 0–1)	0.99953	0.99792	0.99966	0.99879	0.99966	0.99884

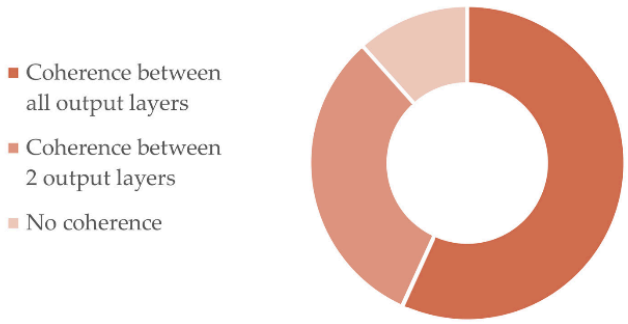

Figure 4. Coherence between suitability mapping output layers based on CLC, LUISA, and OSM.

Fragmentation. The statistical analysis was used to derive an understanding of the degree of fragmentation. As described in Section 3.2, smaller isolated areas were excluded with the sieving function. The patch statistic results (Table 2) show that through the sieving process, the number of patches of the OSM-based suitability map decreased drastically (compared to the other two outputs). The extensive removal of smaller areas can imply a prior greater degree of fragmentation, which was further explored with the landscape division index and may be explained by the fine spatial resolution. The results show that all output layers have a value close to 1, presenting a great fragmentation which can be traced back to the fact that suitable areas are only located along water areas. However, the index numbers show a minor improvement in fragmentation after the removal of smaller areas. Overall, the OSM-based output has a slightly smaller fragmentation rate than the other two layers.

Thematic accuracy and appropriateness. The satellite image validation method highlighted a few differences and similarities between the suitability maps of each of the three layers. Firstly, the fine resolution input layer OSM could include non-built areas close to urban areas as suitable spots, while these spaces can be classified as urban areas for the CLC and LUISA maps (see Figure 5a). Secondly, some suitable areas highlighted the inaccuracy due to the coarser resolution of the CLC layer. Figure 5b presents one example of this inaccuracy, where suitable areas are suggested on vineyards and a road, which were defined as non-suitable criteria and should, therefore, be excluded. Thirdly, it was found that inaccuracy of input layers (e.g., displaced ditches) is carried along to the output suitability map (Figure 5c). Overall, the three output layers showed greater coherence in agricultural areas (exemplified in Figure 5d). In comparison to non-sieved output layers, the sieved output layers show less suggestions along larger rivers, such as the Rhine. Whilst some suggested areas are located along the Moselle, no suitable areas were detected along the river Ahr, which can be reasoned by the high coverage of already existing riparian vegetation

buffering the river. A general coherence between the output files was spotted in agricultural landscapes, which are, at the same time, more homogeneous areas than urban areas.

Figure 5. Results from satellite imagery validation: (**a**) red marked areas presenting potential riparian forest buffers suggested by the OSM-based suitability map, but not by the other two outputs (coordinates: 4120537 3005590: 4124094 3007762); (**b**) red areas present non-appropriate suggested areas by the CLC-based suitability map, but not by the other two outputs (coordinates: 4146529 3027011: 4147856 3027821); (**c**) inaccuracy of input and output layers (coordinates: 4191466 2963021: 4194514 2964882); (**d**) the general agreement of all output layers is marked in green, while yellow presents the agreement of two layers, and red is only one layer (coordinates: 4162673 3014443: 4163541 3014973).

Data storage size and processing time. The data storage size of the three LULC layers varies greatly (ranging from 206.2 MB to 26 GB) for the entirety of Europe, depending on their resolution. However, the suitability output maps are of the same size. For the study area, no considerable differences in processing times were detected, perhaps because the area is rather small (compared to the European region). Nonetheless, the input data storage size is expected to have an impact on the computation time for the entirety of Europe.

5. Discussion

In this study, we tested the impact of different spatial resolutions on the output of the suitability mapping to support our decision of a suitable input LULC layer for the suitability mapping of the NBS Toolkit.

Overall, the results showed a great sensitivity when comparing the suitability maps of different resolution LULC input layers. This was indicated by the different analyses. Firstly, the cell statistics showed that the suitability mapping outputs of coarser resolution layers were more coherent with another than with the fine resolution layer. Secondly, a high sensitivity was detected through the patch statistics in the total size of suggested areas, the number of patches, the degree of fragmentation, and in the coherence analysis of all layers. Thirdly, the qualitative accuracy and appropriateness validation results suggest that the OSM fine resolution layer was more accurate and appropriate than the coarsest layer, especially close to low-density urban areas or houses. This finding aligns with the outcomes of Grafius et al. [19], stating that fine resolution layers are recommended to be used for urban analysis. However, in this study, rural areas were the focus and, therefore, the fine resolution layer showed only minor advantages compared to the coarser layers, based on the satellite imagery validation. In more homogenous land covers and uses (e.g., agricultural land), the coherence between all layers was greatest; thus, for these areas, the usage of coarser resolution layers can be sufficient, considering higher computational processing time of fine resolution layers, but also increasing processing complexity due to working with different data types (e.g., raster and vector). Lastly, the computation showed that there are no major differences in processing time within the study area, but it can be assumed that for computation at the European scale, a difference will become obvious [15].

It can be concluded that the findings confirm the hypothesis that the resolution of LULC input datasets for suitability mapping needs to be determined in alignment with the aimed landscape type (urban or rural), as coarser resolution layers with, e.g., 100 m resolutions may not be accurate enough for highly heterogenous urban landscapes. Furthermore, which Nature-Based Solution the suitability mapping is focusing on needs to be considered. In this study, a large-scale NBS was selected, but for small-scale NBS, such as ponds and basins, finer resolution layers can be more appropriate. Hence, for decision-making on input layer's spatial resolution for suitable mapping, the desired goal (NBS scale and landscape) needs to be taken into account. This conclusion reflects findings in other studies [18,19].

Even though the suitability of data for an intended purpose may not always be defined based on statistical measures [50], we used the results of this study to support our decision-making on the most suitable input layer for the computation of suitability maps for Europe. Based on the results, we utilise the LUISA layer for assessing the suitability of riparian forest buffers across Europe. However, for small-scale Nature-Based Solutions, or for solutions to be implemented in (semi-)urban areas, the toolkit will be using the OSM fine resolution layer.

Finally, it can be recapped that the suitability mapping at the European scale functions as a pre-assessment and, therefore, inaccuracy in mapping may be caused by the coarseness of the input datasets. As we have seen, even the fine resolution layer indicated inaccuracies which could not be prevented. Hence, we argue that a local and context-specific assessment (including, i.e., social, economic, and political criteria) is necessary for in-depth validation and for final decision-making to avoid implications for the environment, society, and overall flood risk [3,51–53].

6. Conclusions

This study was performed to support the development of an innovative toolkit for decision-support on Nature-Based Solutions across Europe. The NBS Toolkit is based on open-source datasets. For many of the NBS suitability criteria, there is only one dataset available at the European scale, but for the land use and land cover, several datasets are openly available at different spatial resolutions. Several studies in other research fields are discussing the influence of spatial resolution on the outcome, but this was not tested in context of the suitability mapping of Nature-Based Solutions. To gain a better understanding on the impact of the resolution on the final NBS suitability map, this study compares the outcomes of three European land use and land cover layers to different spatial resolutions in a test area in Germany. The results of this study suggest that for rural areas and larger scale NBS, coarser input layers can be sufficient, while for urban and small-scale NBS, finer resolution may be required. These results were integrated into the development of the NBS Toolkit and, therefore, the suitability mapping method could be upscaled to Europe. Furthermore, the method will be replicated in other regions, such as in Africa. Overall, this study extended the existing scholarship for NBS suitability mapping.

Author Contributions: Conceptualisation, J.O., J.N. and M.K.; methodology, J.O.; software, J.O., J.N. and S.V.; validation, J.O., M.K., J.N. and H.L.C.; formal analysis, J.O.; data curation, J.O.; writing—original draft preparation, J.O.; writing—review and editing, J.O., J.N., S.V., M.K. and H.L.C.; visualisation, J.O.; supervision, J.N., S.V., M.K., L.S.L., S.D.S. and H.L.C.; project administration, L.S.L. and S.D.S.; funding acquisition, S.D.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request. In case of a request, the authors will provide a citation along with the requested dataset.

Conflicts of Interest: Authors Joy Ommer, Saša Vranić and Milan Kalas were employed by the company KAJO s.r.o. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix 5: Our Climate Story book (serious game)

This version is a draft version (April 2024) of the serious game. The serious game is being developed within the EU-funded I-CHANGE project and will be made available for download on www.citizens4climate.com after it is finalised.

Table of Content

Preface

Have you noticed that our summers are getting hotter, wind stronger, and it does not rain for a long time or it rains a lot in a short time? In the last few years, fires have become so common because the forests run dry without any rain and this scorching heat…

It's a vicious cycle!

The summer heat often covers the city like a cheese bell: our homes get so hot during the day and don't cool down enough at night to let us sleep properly. People suffering from heat strokes, so bad that they need to go to the hospital, and animals and plants are struggling, too. To effectively cool down our cities, we need more green solutions in our neighbourhoods like planting trees and green roofs. To save citizens from dehydration, we need more public water refill stations and strategies for cooling our homes in an environmentally friendly way.

And when it finally rains after a long period of heat - oh what a relief! – but then it often rains too much, so much that our rivers swell up and flood over the riverbanks, often entering residential areas and causing damage to the foundation of our houses and threatening the home of citizens and animals. Imagine if we had ponds located next to the river, they could catch the excess water and save us from the devastating impacts of floods!

There's either too little or too much of everything!

Do you notice the trash that covers our streets and pollutes our parks?! The trash, if not managed properly can release threatening substances to our ecosystems or worsen floods by blocking important water runoff routes. Imagine if our municipality provided proper waste management facilities, and

we start understanding the importance of separating trash – we could reduce the terrible impact that trash causes to our environment and reuse valuable materials.

Apart from the pollution from waste, there is also the pollution in the air due to the traffic of cars, lorries and buses, that push millions of tiny particles into the air which are mostly invisible to our eye but can settle in our lungs and cause long-term damages to everyone's health. In fact, children are the ones who suffer the most! In a recent report, they found that the air pollution around schools is particularly high, causing chronic asthma and other lung diseases. Is this really necessary? Do we really need to put children's health at risk with our behaviour? Imagine the quality of the air and the sense of spaciousness in our city if people were to give up driving cars. Less cars = better air = healthier citizens! Fewer cars = less occupied parking space = more space for trees! So, what are we waiting for?!

Most likely, you don't hear these concerns for the first time, and it can be overwhelming to hear them again and again!

But the point is that if we continue living the way we have been, our life in the city will soon become unlivable. How we live in the urban space does not only affect us, it also affects the entire globe because not only we but especially plants and animals are under stress with rising temperatures due to the emissions we pump into the atmosphere. We cannot undo the damage done by now, but if we come together with sustainable ideas and the willingness to adapt to meet the biggest challenge of our time, we have a good chance to make our cities sustainable, healthy and a safe place to live in the future.

Will you join this challenge?

What you will need for this challenge:

2-5 players which are 10 years or older
90-120 min of time
1 table

Chapter One: Our little world

The world is so big that (as Google says) it would take about 334 days to walk around it. This enormous distance is luckily nothing we ever must do in our daily lives. In fact, everyone is living in a little world compared to the whole big world: Think about how far do you move every day? 1km, 10km, or 100km? Where do you usually move? Within your city, to other cities? Think about which are important points for you in your everyday life! To school, work, to your hobbies, to visit friends or family?

Draw your little world!

Group together with your fellow players and draw the little world you live in on the gridded papers! Now, you are probably wondering how to draw your little world! Don't worry, it doesn't need to be perfect, and you can use a map as a help! This is not a school exam!

Here are some hints (you don't need to follow the order but should go through all steps):

1

Use the 2 gridded papers and put them on the table. You may want to fix them on the table with some tape. Now, you can decide how big your little world is – is it the whole city or just a part of it or a village?

2

Draw the main streets of your little world inside the fields. Don't draw the roads on top of the grid lines!

3

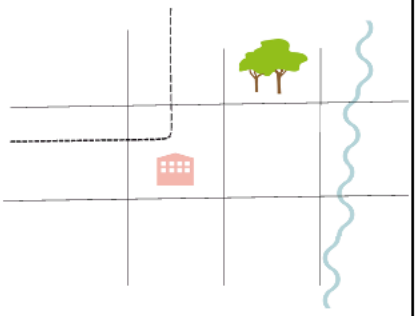
Draw rivers, lakes, fields, railways, and other landscapes (you can also just color the fields differently)!

4

Draw up to 6 important train, metro, tram, or bus stops in the fields as they are in your little world!

5

Draw your homes! Each player can draw the own home into one field! If you don't live in the area, you may draw the train or bus stop at which you usually arrive.



6

Now, draw all places (e.g., school, market, bar, pharmacy, sightseeing points) that are important to you such as your school or the market (use only 1 field for 1 place).

Cut out 3 Place Cards for each player (e.g., cut 15 cards for 5 players).

Now, you can write each of the places you drew on the map (in Step 6) on one back of a Place Card. Make sure that you drew enough places on the map!

Place Card	**Place Card**	**Place Card**
Place Card	**Place Card**	**Place Card**
Place Card	**Place Card**	**Place Card**
Place Card	**Place Card**	**Place Card**
Place Card	**Place Card**	**Place Card**

Chapter Two: Our hazards

What is a hazard? In fact, everything that might be dangerous to us! But here we talk about a hazard which is somehow connected to our nature. Talking in plain words: hazards can be a long episode of hot weather (heatwaves), having water where it is usually not (flooding), having soil or rocks moving down hills and mountains (landslides), having many months without rain (drought), having snow moving down the slopes (avalanches), having fires in our beloved forests (wildfires), or having lightnings striking everywhere (storm). Probably you got the idea about which types of hazards we are talking about here.

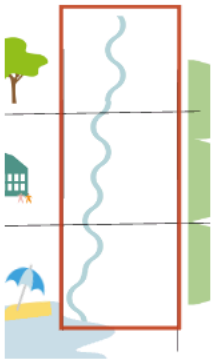
Have a thought in your group about which hazards you have in your little world!

Hazard Card	Hazard Card	Hazard Card
Hazard Card	Hazard Card	Hazard Card
Hazard Card	Hazard Card	Hazard Card
Hazard Card	Hazard Card	Hazard Card

Cut the Hazard Cards out and write each hazard that comes to your mind on the back of one Hazard Card.
(You don't need to use all cards but at least two!)

Now, that you have written down which hazards can happen in your area, we need to think about where in your little world can they happen. For example, when it rains a lot, the river water might rise and comes over the riverbanks. It would be risky to enter these flooded areas because the water can be very powerful and, in the worst case, flush everything away! Here is another example, have you noticed where the air gets really bad? It is probably not in a forest since the trees are actually cleaning the air, but it is rather next to roads where there are many cars driving. These areas with bad air can be very risky for our health! Also, sometimes there is a landslide risk area but for example the mountains are not drawn on your map, so you can draw the risk area on your map.

Now, circle the fields in your little world where these different hazards can happen. Here is an example of how we marked the flood risk area. For some hazards, like snowstorm, there might be no specific risk areas but rather every field would be affected.



Chapter Three: Our solutions

Have you ever noticed that walking through a forest or a park during a hot day is much more pleasant than walking on an asphalt road in a city? The hazards you have written down may become even worse in the future. Did you know that these hazards can happen, but it is possible to make their impact smaller?

Have a thought in your group about what are good solutions to minimise the impact in your area!

This is a rather difficult task. Here are two examples:

- Vegetation in cities can help reducing the temperatures because plants and trees are producing water while breathing (transpiration). This water which is in the air cools the air! Also, trees can provide shadow and have a cooling effect on the area around them.
- Rivers are usually meandering which means that the water moves forward like a snake in a very curvy way! In the past, many rivers were straightened because this way the river would not take too much space and boats also could go much faster! But straight rivers are very sensitive to rain; thus, the water can raise much faster than in a meandering river which basically means that these rivers can cause flooding much faster than natural ones. For this reason, straight rivers are re-naturalised to prevent flooding.

Which solutions to minimise the hazards could be good for your area?

Cut out the Solution Cards and write each solution on the back of one Solution Card!

Solution Card	Solution Card	Solution Card
Solution Card	Solution Card	Solution Card
Solution Card	Solution Card	Solution Card
Solution Card	Solution Card	Solution Card
Solution Card	Solution Card	Solution Card

Are there actually some already in place? Did you consider these solutions when you mapped the hazard risk areas in the chapter before?

We cannot only minimise these hazards, but we can also protect ourselves from them! Think about the recent Covid-19 pandemic! Everyone was wearing a mask to protect themselves from the dangerous virus. Also, in Asia, people are commonly wearing masks to protect themselves from air pollution! Another example is to put on sun cream and wear clothes to protect us from the sun.

Which things could protect you from the hazards in your little world?

Write each protection measure on the back of one Protection Card!

Protection Card	Protection Card	Protection Card
Protection Card	Protection Card	Protection Card
Protection Card	Protection Card	Protection Card
Protection Card	Protection Card	Protection Card
Protection Card	Protection Card	Protection Card

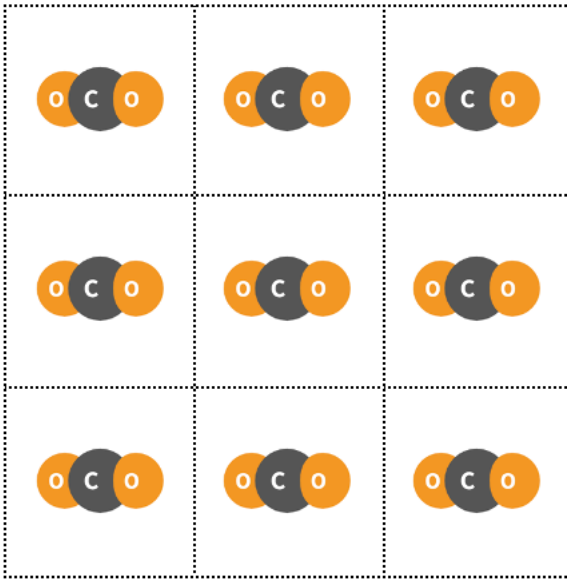
Chapter Four: Our emissions

What is emission? It's all the gases (and other molecules and compounds) we put into the air, often without realising the consequences they have for our environment. Emissions are also like the behind-the-scenes actors shaping our climate. Whether it's the smoke from factories, the exhaust from countless cars, or the gases from power plants.

So, how does this relate to hazards? As we pump more carbon (dioxide) into the atmosphere, they are helping to warm our world more than they should. These rising global temperatures become the leading actor, triggering events like flooding.

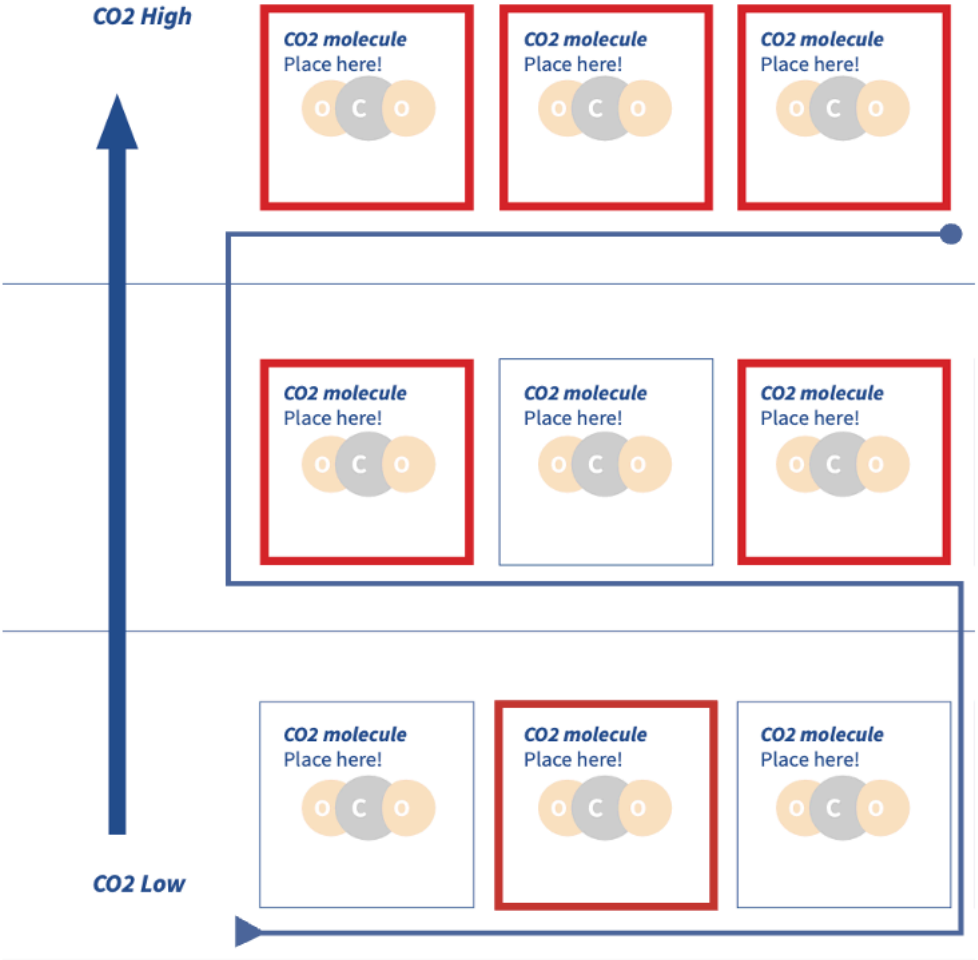
Do you know which of your actions cause emissions?

Greenhouse gases like carbon dioxide (CO_2), produced by our activities such as burning fossil fuels and cutting forests, act as pivotal plot points in Earth's climatic story. Their excessive emissions intensify the planet's temperature, giving rise to hazards like heatwaves and storms. These environmental twists underscore the urgent need to reshape our narrative toward sustainable practices and prevent further climatic challenges.



The more CO2 (and other greenhouse gases) we produce, the more the atmosphere warms up. Because no-one can surely say how much we will produce in the next years, we don't know exactly how much the world will warm. But to have an estimation, scientists use different emission scenarios to calculate the changes in climate. Usually, they work with 3 scenarios: best, medium, and worst. Below, you can see these three scenarios and also what is the impact of them: the more CO2 in our atmosphere means more hazards which are triggered in the red fields.

Cut out this Climate Scenario Scale below!



Chapter Five: Let's play for a change

Sorry, but there a yet few more steps to do before starting to play!

1. Who are you? Each player takes a Player Card and draws their playing symbol, face, or similar on the back of it.

2. Take the Trash Cards and think about where in your little world is always a lot of trash laying around (while it should be in a bin). Place the cards on the squares where you think these are trashy areas.

3. What do you usually do each day? Turn all place cards around and shuffle them. Each player can draw three cards (4 cards if only two players are playing) which will tell them what they usually do during the day. More about this will be explained later!

4. Each player gets 2 leaves (from the next page) at the beginning. For what these leaves will be used, will be explained shortly! Put two leaves on the Community Fund and all other leaves on the Bank.

5. Put all CO_2 cards on one pile and place the climate scenario scale so that everyone can see it.

Now, you are all set!

Cut out these cards out and distribute them!

This is how it goes…

Who wins? The game ends either when:

- a player finishes the own to do list (player wins)

  OR

- the CO_2 level is at the highest point (everyone loses)

Who starts? The person who cycled most recently can start and then it goes around the clock.

How do we move? You start in the field of your home, a train station or similar. The aim is to move to each of the 3 drawn places of your interest. Once you have reached all places, you will have to go back to your starting point to win.

Each time when it is your turn, you can make one move. There are different types of moving and you must decide which one you use.

Types of moving:

- Walking: you can move one field (not diagonal!)
- Cycling: you can move two fields (not diagonal) but only on roads
- Using public transport: you can move from one (public transportation) stop to the next stop in one turn. For using public transportation, you must pay a ticket (put 1 leaf to the community fund). You can use public transportation during the whole game.
- Driving: using the car, you can move 5 fields on roads during your turn. One car ride (5 fields) costs 1 leaf but produces 1 CO_2.

If you cannot move for any reason, you may just wait and enjoy the landscape views until the next round!

Climate Scenario Scale: Each time CO_2 is produced, the player needs to add one CO_2 molecule on the Climate Scenario Scale starting at the bottom left. The next molecules will be placed along the line.
Every time a CO_2 tile is put on a field with a red frame, a hazard is happening!
If all molecules are put on the scale, everyone loses the game!

Solutions & Protections: At the beginning of each round, the players can discuss together whether they want to realise one Solution Card or buy a Protection (Card) for everyone. One player can be appointed as the discussion moderator. If all players agree on a Solution or Protection mechanism, it can be bought with the leaves from the Community Fund. A Solution Card costs 2 leaves, and a Protection Card costs 1 leaf.
Realising a Solution Card means that the hazard – when it was drawn – would be prevented by the natural elements. For example, the flood Hazard Card was drawn but the river was re-meandered before, all people in the flood risk area will be save and do not have to miss one round.
Realising a Protection Card is similar. For example, when the air pollution Hazard Card was drawn, but masks were bought for everyone before, then everyone in the air pollution risk area do not have to miss a turn and can continue to play.

Hazards: When a CO_2 molecule was put on a red framed field on the Climate Scenario Scale, a hazard happens: first turn around all Hazard Cards, then shuffle the cards, and the player who put the last CO_2 molecule must draw one of the cards. The drawn card will tell which hazard is striking. Every player who is in the risk area of this hazard cannot move for one round.
In case of a Landslide, Flood or Marine storm, the risk zone cells are blocked for 1 turn, too. This means that no-one can move into a risk zone of the striking hazard. After a hazard has

been striking, add the used hazard card to the hazard pile and shuffle it.

Trash Cards: Whenever, a player gets on a field (whether stopping there or only passing by) where there is a Trash Card, the player can pick up the Trash and receives 1 leaf (from the Bank) as a bonus for the environmentally friendly behaviour.

Leaves: Each player gets 2 leaves at the beginning and 2 leaves will be in the Community Fund. The rest will be put on the Bank. The players can use 1 leaf to travel by public transportation to one destination or for a car ride. When a leaf was paid for the transport, it will go into the Community Fund. With the leaves in the Community Fund, all players together can buy a Solution Card (2 leaves) or Protection Card (1 leaf).

Community Fund: The Community Fund is a pot of leaves that are provided by the municipality to the citizens to take actions against climate change. The Fund gains leaves when a player uses public transportation or a car. The leaves in the Community Fund can then be used to buy Solution or Protection Cards.

Chapter Six: Optional game modes

If you want to give a twist to your gaming experience, you may want to try one of these additional game modes:

1. Moving cards

At the start of your turn, draw one movement card. This card will represent your movement possibilities for the turn and give you three options. Choose one and move your placeholder accordingly:

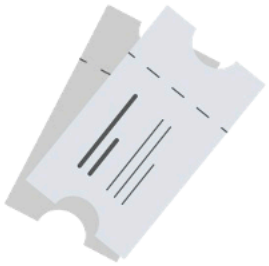
Walking: move by the specified number of fields (not diagonally!)

Cycling: move by the specified number of fields (not diagonally!) and ONLY on roads.

Driving: move by the specified number of fields (not diagonally!) and ONLY on roads. Additionally, you need to pay the number of leaves and rise the CO_2 level by the amount specified on the card (if you don't have enough leaves, you cannot use this option).

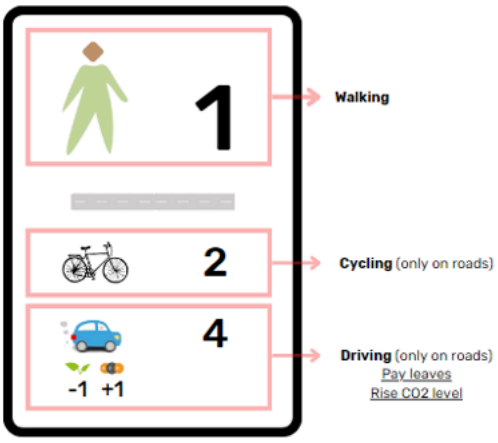
Public Transportation

If you are close to a public transport stop and you have a ticket subscription, you can decide to use this transit *instead* of the above movement options.

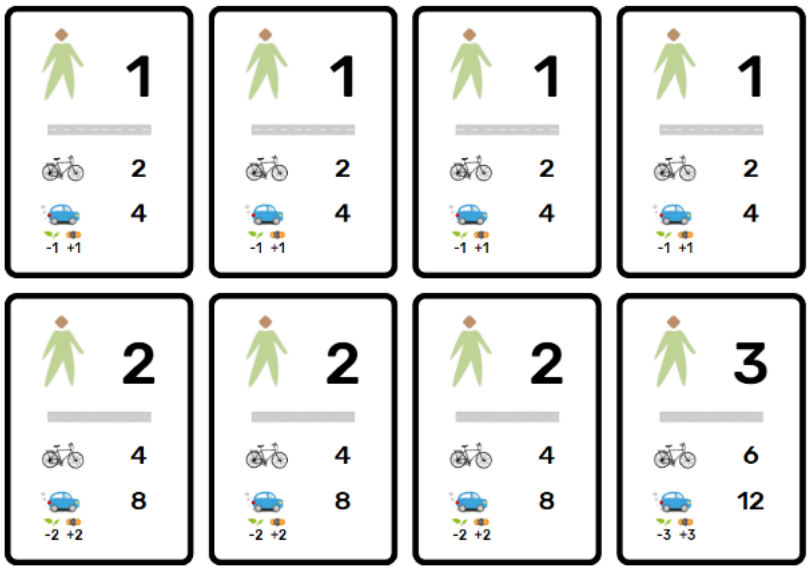


If you choose this option, discard your movement card, and move directly to the next public transport stop on the line. To buy a ticket subscription, simply pay 1 leaf to the community fund and you will be able to use public transportation for the whole playthrough!

Movement Cards



You cannot move diagonally!



2. Team VS Team

In this game mode, two or more teams will compete each other to finish all their tasks first.

Preparation:
divide the players in different groups, possibly creating non-adjacent teammates.

Changes to gameplay:
In this game mode the game ends either when:

- all players in a team finish their own to do list (teams wins)

  OR

- the CO_2 level is at the highest point (everybody loses)

Tasks:

If specified on the task cards, players can have the possibility to complete their teammates tasks.

Four or more players is suggested.

3. Co-op VS Time

In this game mode, all players cooperate against time.
Finish all tasks before a set number of rounds!

Preparation:
Based on board size and number of players, decide the maximum number of rounds limit.

Changes to gameplay:
In this game mode the game ends either when:

- all players their own to do list (everybody win)

  OR

- the CO_2 level is at the highest point (everybody lose)

  OR

- The maximum number of rounds is reached. (everybody loses)

Tasks:

If specified on the task cards, players can have the possibility to complete other players tasks.

Three or more players is suggested.