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Barriers and ways forward to climate risk management against indirect effects of natural disasters: A case study on flood risk in Austria

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ABSTRACT

Natural disasters, such as floods, can have severe consequences, especially as economies are becoming ever more interlinked and complex so that the cascading effects of disasters can amplify direct impacts. These trends are expected to continue in the future due to climate change and changing socio-economic structures. It is therefore important to promote climate risk management strategies that also deal with indirect effects due to natural disaster events in a proactive manner. However, there is a lack of studies which investigate the agents involved in climate risk management geared towards the indirect effects of disasters and how these indirect effects are or can be dealt with. We address this gap via a detailed case study of the Austrian flood risk management apparatus. Based on a detailed stakeholder analysis, we compile a stakeholder map of those potentially involved in indirect flood risk management as well as the relationships among them (or the lack thereof). We further discuss current and future indirect risk management strategies and corresponding implementation barriers. Finally, based on the results obtained from the stakeholder process, we discuss and suggest possible ways forward to overcome these barriers to enable proactive management strategies for indirect climate risks. We find that although indirect risks are being considered in the Austrian flood risk management, they are managed to a marginal degree. To remedy this, we call for increased efforts in data collection, modelling and awareness raising and the revision of current financial as well as institutional structures. Greater focus should be put on interdependencies within systems as well as the adoption of long-term visions for establishing more integrated climate risk management against indirect effects.

1. Introduction

Losses due to natural disasters are on the rise, both in terms of fatalities as well as in economic terms (EM-DAT 2018, Munich Re 2020, Swiss Re 2020). This growing trend towards ever increasing economic damages is expected to continue in the future due to climate and demographic change: With more people and assets accumulating in hazard-prone areas and events becoming more frequent and intense, their impacts are likely to grow as well (Schipper et al., 2016; Aon 2020; Blöschl et al., 2019). Especially flood events are showing a worrying picture in this regard. In the last years, floods have been the most frequently occurring natural disasters

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affecting more people than any other type of disaster (UNDRR/CRED, 2020) and, according to climate projections, will do so in the future. Especially Europe's alpine region expect an increase of annual precipitation (Majone et al., 2016) as well as a shift in snowmelt flows in glacial regions (earlier and larger in volume) (Bard et al., 2012). This leads to an increase in annual discharge maxima, their frequency of occurring and changes in seasonal flood patterns (Madsen et al., 2014; Castellarin and Pistocchi, 2012; Wagner et al., 2017). The severity of flood events has only recently been shown by those occurring in Germany in July 2021, which caused more than 160 deaths (Cornwall 2021). Climate change and other anthropogenic influences, such as land use change, river regulations or levees, are one of the main drivers behind these developments (Castellarin and Pistocchi, 2012; Madsen et al., 2014).

Also in terms of economic damage, floods are at the forefront showing the second highest loss levels after storms worldwide (UNDRR/CRED, 2020). Before and after a disaster strikes, the focus of risk bearers is usually on dealing with the event's direct damages, however, indirect damages have been gaining importance with regard to risk management (Handmer et al., 2020; Reichstein et al., 2021). Indirect damages can include monetary components, such as reduced economic production or income due to business interruptions, supply chain disruptions, loss of labor or increased indebtedness, but also non-monetary aspects such as changes in welfare or equality (Hallegatte and Przyluski 2010). Especially in industrialized countries, indirect damages can potentially match or even exceed the direct ones (Koks et al., 2015; Dottori et al., 2018). As industrialized economies are strongly connected via international trade and as supply chains grow more complex, the cascading effects of disasters can critically burden not only the affected region's economy but also those of neighboring regions (UNDRR 2019; Challinor et al., 2016; European Environment Agency 2017). As concerns about these indirect effects are rising, strategies to prevent and manage indirect risks are in urgent demand.

Many studies now exist on how to model the indirect damages caused by natural disasters (see Botzen et al., 2019, Naqvi et al., 2020 for a review). Meanwhile, research investigating how policy makers could explicitly deal with these damages on the ground is lacking. Even more so, there is little experience with implementing public management measures for indirect risk. Recognizing the complexity of direct risk management (RM) (Kruczkiewicz et al., 2021), it is not surprising that indirect risks are overlooked: Indeed, in most industrialized countries, direct RM is still the focus of disaster risk reduction and a large part of research and investments are made to further develop this field. In regard to flooding, for instance, structural protection is still favored over non-structural measures (Meyer et al., 2012).

The paper at hand contributes to this increasingly important yet understudied research area of how indirect risks from natural disasters are being and could further be proactively integrated in public flood risk management (FRM) and, by extension, climate risk management (CRM). We shed light on the issue via a detailed case study of current processes within FRM in Austria. The country was chosen due to its well-developed FRM and complex, interconnected economy, while being located in Europe's Alpine region. Many previous studies have tackled various issues of the Austrian FRM, for instance, its governance structure (Ceddia et al., 2017), people's risk-reduction behavior (Hanger et al., 2018), alternative financing options (Rauter et al., 2020), policy agendas that promote interregional co-operations (Thaler et al., 2020) or the stakeholder landscape of direct FRM in Austria or particular provinces (Schinko et al., 2017; Leitner et al., 2020). For indirect FRM, however, studies are lacking and a stakeholder landscaping has not yet been done, so our study aims to close this research gap. Based on this analysis, we further discuss the results within a broader context of current management approaches and contribute to the literature by suggesting ways forward as to how to integrate direct and indirect FRM, especially for governmental institutions as decision-makers.

The paper is organized as follows: Section 2 presents the methodology applied for the analysis. Section 3 introduces the stakeholder landscape as an intermediate results and section 4 gives results, which are then discussed in detail and put in a more general context in section 5. Finally, the conclusions we draw from our analysis are presented in section 6.

2. Methodology

We first start with some overall considerations of indirect RM issues and how they can be embedded within CRM. In the policy domain, CRM refers to the process of integrating data on the trajectory of climate change and resulting events into decision-making processes (Travis and Bates 2014). It, therefore, describes the combination of disaster risk management (DRM) and climate change adaptation (CCA), i.e. the adjustment to (expected) changes in climate with the goal of minimizing the resulting damages and/or maximizing the advantages of said change (IPCC 2018). CRM has become a pressing issue for governments and policy makers around the world. Its implementation, however, still faces many challenges (Islam et al., 2020), one of them being the management of indirect damages.

A crucial topic which thus emerges in CRM is the importance of proactively considering indirect risks caused by natural disaster events, especially for very inter-linked and complex economies (Reichstein et al., 2021). We argue, therefore, that the concept of indirect RM, which tackles the indirect effects of natural disasters, forms a natural extension to direct RM since indirect risks can only occur in presence of direct ones.

Within risk-informed approaches (Aven et al., 2020), direct RM is grounded in the return periods of natural hazards and the direct exposure and vulnerability of a system's elements to the effects of a hazard event, which subsequently determine loss levels. Meanwhile, it is a system's level of connectedness among *all* the elements within the system which plays a role in indirect FRM: It determines the vulnerability of the system and, thus, the magnitude of the damage incurred (see Hochrainer-Stigler and Reiter (2021) for details). This means that for indirect risks, also elements in the system outside the affected area can be impacted and that loss levels grow higher with increasing interconnectivity (Hochrainer-Stigler and Reiter, 2021).

By introducing indirect FRM as a pillar within DRM, one not only highlights the importance of managing these risks but also indicates that this is a field within the RM process which requires specific attention and management strategies on its own. Direct and indirect FRM together with CCA measures, we argue, result in holistic CRM (see Fig. 1) aimed at the total, i.e. direct as well as indirect damages of any natural disaster.

In this context, we analyzed how indirect FRM can actually be embedded within direct risk-focused processes, especially with governmental institutions as decision-makers. We did so via a detailed case study of current processes within FRM in Austria looking at three distinct aspects: First, we determined risk awareness levels of stakeholders in the Austrian FRM apparatus concerning indirect flood risks and acquired an overview of existing management instruments. Second, we established the difficulties and barriers stakeholders face in implementing current or potential future management instruments of indirect flood risks. And, third, we identified ways forward for a truly holistic and integrated CRM against indirect effects.

We followed a two-step qualitative approach for a formal analysis of these three aspects as depicted in Fig. 2. Additionally, we embedded the results found in recent suggestions on direct FRM and CRM strategies for Austria (Schinko et al., 2017; Leitner et al., 2020) and extended these and similar ideas for direct to indirect risks.

The starting point of our study was a thorough analysis of the focus and limits of the current governance practices of the Austrian FRM. Specifically, we performed a survey of peer-reviewed and grey literature, i.e. publications by various Austrian federal ministries or other (research) institutions (BMNT, 2018), on risk preferences and management policies regarding both direct and indirect risks of natural disasters in Austria (Fig. 2, Step 1). Additionally, we applied this literature survey and internet research to compile a list of stakeholders and key decision makers (possibly) involved in indirect FRM in Austria and, thus, relevant for our stakeholder process (Fig. 2, Step 2). Stakeholders were carefully selected on basis of their key operational functions within the Austrian FRM and included actors on the national, regional as well as local level. Further stakeholders of interest were added to the list during the interviewing process via snowball sampling[1]. An additional focus group meeting was held to feedback results to key decision makers involved in the process.

In total, 26 semi-structured interviews and one focus group meeting were conducted. If permission was given, the interview was digitally recorded and, afterwards, summarized and coded (see Supplementary Materials for the interview questionnaire and further information on the recruitment process). The resulting text, then, formed the basis of a content analysis to identify patterns as well as differences in the contents, foci and narratives among the different stakeholders (see Fig. 4 for the actual coding). The interviews and meeting helped obtaining a clear picture on stakeholders' responsibilities and positions within the network of Austrian FRM. Additionally, light was shed on stakeholders' risk awareness, current governance processes and instruments as well as implementation barriers and opportunities for indirect FRM and CRM.

To formally structure the stakeholder interaction, we prepared a semi-structured interview to answer the following research questions:

i. Do stakeholders feel affected by indirect risks? Do stakeholders expect climate change to influence these risks? (risk perception)
ii. Which measures are already being taken against indirect risks and what are further policy and practice options? (risk management)
iii. Which difficulties and/or obstacles do stakeholders perceive within the Austrian FRM and how can they be tackled? (difficulties and/or obstacles in RM)

3. Context of the case study: Potential stakeholders within the Austrian indirect FRM

Before discussing our results, we present the identified stakeholder landscape. This step serves as an important intermediate result. Fig. 3 shows the corresponding map including relationships among stakeholders (interviewed = bold). The map was generated based on our literature research of peer-reviewed and grey literature as well as the information gained in the interviews.

As one can see, the Austrian FRM is organized into a complex network of authorities at the federal (green), provincial and/or regional (orange) as well as local level (yellow) with international actors (blue) also playing a part in providing humanitarian or financial assistance and information. Stakeholders' respective competences and responsibilities are defined by a set of laws and can, for a large part, be assigned to steps along the disaster management cycle, i.e. disaster prevention, disaster preparedness, disaster management and recovery.

Most developmental competences and infrastructure management responsibilities lie with the federal government while spatial planning and water management is implemented at provincial and municipal levels. Key decision makers of the federal government are ministries such as the Ministry of Agriculture, Regions and Tourism (BMLRT, water management and FRM), the Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK, flood defense), the Ministry of Interior Affairs (BMI, coordinating RM operations and instruments), the Ministry of Defense (emergency assistance), the Ministry of Education, Science and Research (BMBWF, meteorological services) and the Ministry of Finance (BMF, budgetary issues). Many of these ministries have individual departments operating in the provincial governments (colored orange in Fig. 3).

Preventive FRM is the main responsibility of different authorities operating in regional departments (see "prevention" in Fig. 3): The ViaDonau (a company operated by the BMK) maintains the waterways Danube, March and Thaya; the Torrent and Avalanche Control (WLV, a subordinate agency of the BMLRT) manages wild streams; the Federal Water Engineering Administration (BWV, also part of the BMLRT) manages all other water bodies. The BMK also supervises the Federal Environment Agency, an environmental expert organization or assigns hydraulic engineering projects to civil engineers.

[1] Snowball sampling is a research technique in sociology and statistics grounded in expert interviews where current participants identify future, additional ones and so the sample group grows in size, much like a rolling snowball Prell et al. 2008.

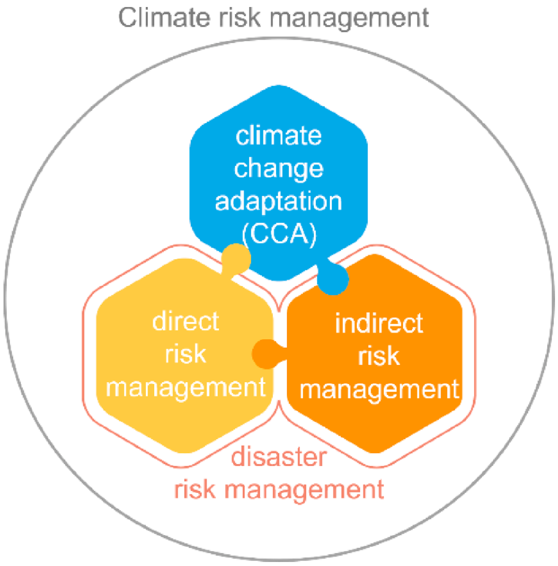

Fig. 1. Schematic representation of the combined efforts of direct RM, indirect RM and CCA to form holistic CRM against the total effects due to natural disaster events.

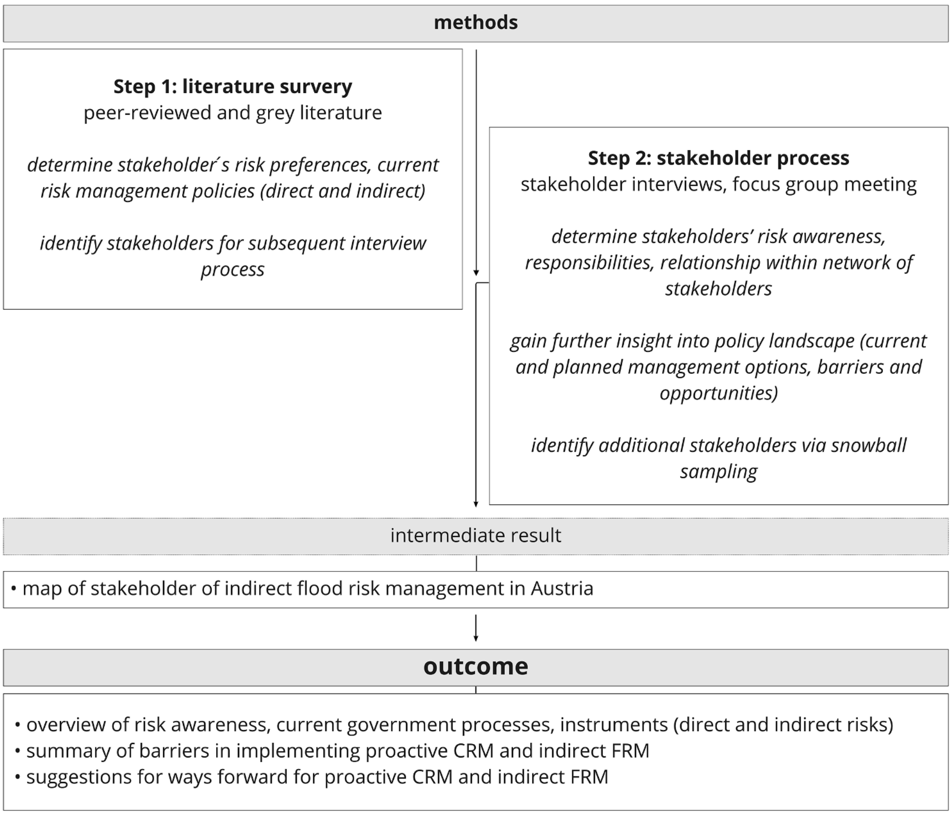

Fig. 2. Overview of the main structure of the two-step methodological approach applied (with the main instruments and overall goal given for each step) and its outcome.

Crisis and disaster preparedness and response operations (see "preparedness & response" in Fig. 3) are largely the responsibility of the provinces and bundled at the respective departments for civil protection. There, a number of agencies and partners operating on provincial, regional and local levels are coordinated which include rescue organizations, units of educational programs led by the

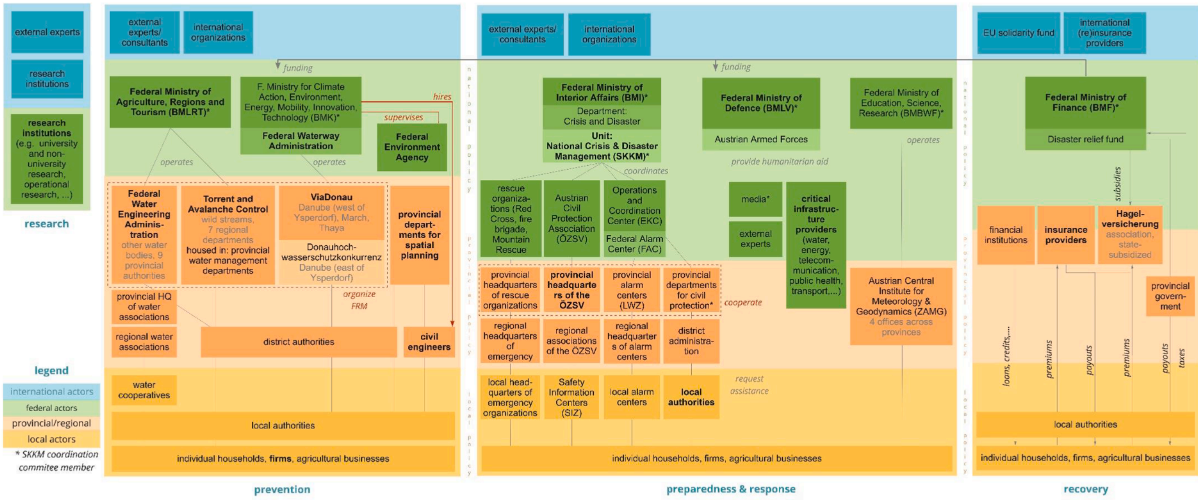

Fig. 3. Key stakeholders for indirect FRM in Austria. Clusters (prevention, preparedness & response, recovery) represent the field of disaster management stakeholders' (main) competences fall within, arrows explain relationship and responsibilities within the stakeholder network.

Austrian Civil Protection Association and centers of the Austrian warning and alarm system. In case of a flood event, the crisis and disaster management efforts of the federal and provincial authorities are coordinated by the National Crisis and Disaster Management unit (SKKM) housed in the department for Crisis and Disaster Management of the BMI.

The funding of FRM measures is provided by the federal state, which makes the Ministry of Finance (BMF) (see "recovery" in Fig. 3) a major player in the Austrian FRM. It houses the Austrian disaster relief fund, a financing tool which provides funding for preventive measures and financial aid for private households (see section 4.2). Additional key players in the Austrian FRM are financial service providers (e.g. insurance companies, banks) and providers of critical infrastructure: from energy to water suppliers, transport, communication or public health providers. Furthermore, research institutes, both national as well as international (see "research" in Fig. 3), make an essential contribution to knowledge and technology transfer for advancing the state-of-the-art in FRM.

4. Results

We now focus on the stakeholder analysis used for determining where links to indirect FRM exist and where management tools might already be implemented or planned that can be adapted for indirect FRM. The main insights gained during this process are clustered and presented in Fig. 4, where each research question corresponds to a column (i.e. column 1 corresponds to research question 1, …). The items presented in these columns are equivalent to the codes used for the content analysis. Additionally, column 4 shows the underlying themes behind the difficulties and obstacles identified, while column 5 gives an overview of the suggested ways forward we formulated and which are discussed in detail in section 5.

4.1. Risk perception

Our study found that awareness levels of stakeholders for indirect damages caused by floods are, in general, very high with the majority of interview partners considering indirect damages and, by extension, their management to be important. Particularly those stakeholders involved in the prevention and recovery phase of the FRM cycle as well as private business owners are concerned about managing indirect flood effects. Meanwhile, stakeholders of the response phase of the FRM cycle are aware of indirect risks but might not assign their management high priority as their responsibilities lie with providing quick disaster relief to those acutely and directly affected.

When inquiring about whether stakeholders are tackling indirect FRM, only 12 out of the 25 stakeholders (see Fig. 4, column 1) acknowledge that indirect damages currently play a role in their scope of responsibilities, which span from documenting to preventing indirect damages. These lie with, for instance, insurance providers, researchers, risk managers or those involved in cost-benefit analyses. For the other half of stakeholders, indirect damages do not (yet) play a role for various reasons. One repeatedly mentioned reason is that integrating indirect damages would simply be beyond stakeholders' remits. For additional two stakeholders, indirect damages would, in principle, matter greatly, however, a lack of complete and/or reliable data prevents them from considering indirect damages in FRM.

With regard to climate change, the vast majority of stakeholders (21 out of 25, see Fig. 4, column 1) expect flood risks to change, even though these effects and the direction of change are still uncertain. Since the way in which climate change will affect the water regime cannot yet be definitively determined, few adaptive measures are being taken and even fewer address the years after 2050.

Fig. 4. Summary of the findings of the content analysis of the stakeholder interviews (items in columns 2 and 3 correspond with the coding protocol used). Columns 1 to 3 present the findings for research questions i-iii. Column 4 shows the underlying and unfolding themes behind the difficulties and obstacles within the Austrian FRM as identified by the stakeholders, while column 5 presents the ways forward that were mapped out.

4.2. Present and future indirect risk management strategies

Although awareness levels of stakeholders of indirect damages are high, only few instruments are currently in place that could potentially tackle them. Additionally, there seems to be a lack of clarity as to who is/should be responsible for planning and implementing indirect FRM. Of those instruments named and already in place, the most important ones include insurance against indirect damages, cost-benefit analyses for risk reduction, critical infrastructure protection and (inter)national financial aid. In what follows, we discuss the above management instruments with a focus on indirect FRM.

Insurance: Indirect FRM instruments already in place include, for instance, insurance products against indirect flood risks such as business interruption insurance offered to firms and business owners. Similarly, individual households can purchase private insurance against flood risks. Since insurance is not available to all or unaffordable, businesses often (have to) create their own captive insurance to circumvent this problem or private homeowners go uninsured (and rely on funds from the Austrian disaster relief fund). According to estimates, the market penetration of flood risk insurance systems in Austria is low at approximately 10–25% (Aakre et al., 2010). Some stakeholders have been arguing for mandatory insurance against natural hazards as a potentially effective option to reduce indirect damages. This, as far as suggestions go, could be introduced as an addendum to the already existing fire insurance and could remedy many of the difficulties stated above (for details see section 5.4).

Cost-benefit analyses: Indirect damages play a role in cost-benefit analyses used in the decision-making process concerning flood protection, where it is decided which measures are to be realized and at which priority. Here, indirect damages are captured in the benefit figures where they are qualitatively described (e.g. in terms of loss of value creation in the affected region within an economic sector), while the cost-side is quantitatively assessed. Such estimates, however, do not extend beyond the region, much less to the macroeconomic level.

Stakeholders mentioned that risk analysis processes are to be expanded in the future so cadastral information, population density and land-use planning schemes play a role in the planning of FRM measures and in disaster response. As determining the losses for a CBA is a lengthy and slow process, revisions are planned to automatize the process in the form of a mark-up factor, i.e. a fixed daily rate for each production day lost. Additionally, there is a project underway to build a nationwide database of loss events and data (CESARE; https://projekte.ffg.at/projekt/3307382) using the combined efforts of several scientific institutions and ministries, their data and model results. While the collection of direct losses lies at the heart of the project, there are also efforts to gather information about indirect damages of natural disasters.

Critical infrastructure protection: Critical infrastructure protection has been part of the Austrian legislative framework by way of the Austrian Program on Critical Infrastructure Protection (APCIP) since 2008. THE APCIP urges CI providers to make their distribution systems as impervious to harm from natural disasters as possible. This is accomplished using organizational as well as technical measures. In the past, efforts have been made to increase infrastructure security along major transportation routes and should, according to stakeholders, also be extended to minor routes in the future. For electricity suppliers, as our study showed, the biggest challenge in the event of a flood is power distribution (rather than generation). Therefore, suppliers are currently tackling this issue by identifying service priorities and strategies to quickly substitute and restore energy provisioning.

National financial aid: The Austrian disaster relief fund was established in 1966 and consists of revenues from income and corporate tax and taxes on capital yield (1.1% of the federal share). It is Austria's most important instrument financing public DRM with the majority of the fund being allocated to preventive measures. Additionally, the fund plays a vital role as an ad-hoc, post-disaster recovery instrument, allocating payments to private households in affected areas. Payments normally cover between 20 and 30% or, in extreme cases, up to 80% of losses incurred (BMF, 2012). This financial assistance helps affected households recover quickly and, therefore, reduce indirect risk. However, despite providing much needed assistance to those affected, several problems can be related to the fund which are discussed in section 4.3. In addition to payments from the Austrian disaster relief fund, financial assistance form the government can also take the form of loans and tax relief (see Fig. 3).

International financial aid*:* A similar fund but on the Pan-European level is the European Union Solidarity Fund (EUSF) (see Fig. 3) which was set up in 2002 to assist in the post-disaster recovery in European regions or countries. Financial aid is granted when a country's or, under exceptional circumstances, a region's uninsurable damage exceeds a particular threshold. Therefore, grants aim at coping with high damage levels ensuing extreme disasters and assisting in financing emergency operations necessary in the immediate post-disaster phase (Kołodziejski, 2020). There are ideas to couple the payment with flood risk reduction practices which should help in reducing future direct risks – the reduction of indirect risks is not yet planned (Hochrainer-Stigler et al., 2017).

4.3. Difficulties and obstacles

According to Aubrecht et al. (2013), maladaptation or false adaptations to the natural environment are at the root of damages caused by natural hazards. Especially societal factors play a major role here, including inadequate development and land use planning, unsuitable regulations regarding building techniques and materials used and people's insufficient levels of awareness and preparedness. All of these issues, and several more, were identified as obstacles in the Austrian FRM (see column 3, Fig. 4). They were grouped according to their underlying themes (column 4) which are addressed in this section. Additionally, each of these obstacles simultaneously presents an opportunity for enhancement (column 5, discussed in section 5).

Indirect damages are inherently linked to direct ones, i.e. indirect damages can only occur in association with direct ones. As a result, indirect FRM and the barriers encountered there are linked to those experienced in direct FRM. Therefore, the difficulties and barriers in the Austrian FRM are not necessarily solely linked to indirect damages but to direct ones, too.

Data gaps: One of the biggest obstacles to overcome is the lack of (reliable) data on indirect damages of past flood events.

Stakeholders argue that determining the direct damages of past events faces difficulties, therefore, ascertaining the indirect ones is all the more intricate (for instance, determining regional shifts in value creation has proven difficult). On small scales, i.e. local or in-house, data collection on damages is taking place, such efforts are, however, in no way comprehensive nor necessarily meant for public use, but rather for in-house documentation or local planning purposes. Even more fundamentally, there is a lack of definition of what indirect damages encompass, i.e. whether they include follow-on effects of the economy, health and societal effects, effects on ecosystem services, etc.

While these data issues remain, predictions and risk analyses about future damages are too uncertain to function as bases for developing management approaches, stakeholders claim. This leaves them feeling constrained in their decision-making. The same holds true for studies on the expected effects of climate change in Austria, for which stakeholders expressed interest. Especially studies on compound events or the combined impact of temporally and/or spatially dependent processes, such as that of natural hazards and climate change, are of interest as they facilitate improved risk analyses, predictions and decision-making (Zscheischler et al., 2020; Zscheischler et al., 2018).

Lack of systems perspective: Although there has been a shift towards a broader variety of FRM options in Austria, the majority of measures taken are structural ones (Nordbeck et al., 2019). Such one-sided approaches open up the way for path dependencies and dismiss the temporal and spatial dependencies involved as well as the diversity of drivers of natural hazards (such as climate change). Several stakeholders referred to little consideration for the ecological effects of FRM measures and called for environmental protection and sustainable development to feature more in the current FRM strategy ("we are building houses on our damage-free future[2]"). A central and recurring issue in that respect was that of spatial planning. Spatial planning as a management tool merges political, social, economic and environmental interests, making it a powerful instrument but also a source of conflict (van Assche et al., 2013). Stakeholders agree that passive flood protection measures would be the most effective and sustainable flood defense and argue for changes in land use planning, i.e. stricter zoning regulations and a decrease in land consumption.

Lack of preparedness and awareness of the public: Stakeholders emphasize that awareness of flood risks among homeowners is lacking regarding their frequency, underlying causes as well as individually taken mitigative measures. As a result, flood risks and the human component in them are systematically underestimated. With flood risk awareness being low, people are even less conscious of the necessity of CCA. Therefore, people often live with a false sense of security and underestimate their risk, disregarding the fact that, even after structural flood management measures are being taken, residual risk exists and is exacerbated by climate change.

Unsustainable financial aid program: As has been established before, the current structure of the Austrian disaster relief fund encourages moral hazard since homeowners struck by disaster are, at any rate, provided with financial support. As research has already shown (Schinko et al., 2017; Prettenthaler et al., 2015), this type of disaster financing will become unsustainable in the future as the reserves of the Austrian disaster relief fund, as it is organized now, will not be sufficient to cover predicted future losses. Other studies compared the current compensation scheme with that of insurance and have found insurance-based approaches that facilitates risk reduction to decrease pressure on Austria's public spending (Unterberger et al., 2019). Payments from the Austrian disaster relief fund are not tied to any proactive FRM measures and only in some provinces there is a limit to the number of payments to be received from the fund (e.g. no disaster relief for owners of assets thrice damaged). Limiting the number of payments which can successively be received should be enforced nationwide and private risk financing and mitigative measures should be encouraged to help avoid maladaptation which, over the years, can develop into cost traps. Therefore, awareness should be built for the necessity to implement building back better strategies which push innovation and adaptation and, thus, build resilience.

Stakeholders have claimed that homeowners often find themselves under extreme financial pressure as payouts from the disaster relief fund only cover a fraction of the damages incurred (as it is designed to), sometimes making them dependent on spontaneous donations collected after a disaster has hit. Financial aid thus raised can, according to stakeholders, be distributed more fairly as local authorities are more aware of who is most in need of help. However, such aid is also more volatile as it depends on the public's willingness to donate. A more just and certain form of aid could be flood insurance programs. Although such programs already exist (see section 4.2), their availability and affordability is limited, especially for those living in an area at high risk of flooding. Additionally, a lack of awareness of flood risks and moral hazard due to the Austrian disaster relief fund, which currently functions as a substitute for insurance, has flood insurance at a low market penetration. Introducing a comprehensive natural disaster insurance program would remedy this problem, alleviate the pressure on public budget and could be instrumental in increasing individual awareness. Amongst the reasons for why a compulsory natural disaster insurance program has not yet been introduced before, even though the groundwork and research on its advantages and disadvantages has been done (see Prettenthaler and Albrecher, 2009), is that it is rather unattractive for political purposes.

Institutional barriers: In the Austrian FRM, competences and responsibilities are strictly distributed among federal and provincial/local government agents (see Fig. 3). Alongside the benefits which this structure of FRM yields, also barriers are created in the overall coordination of FRM. Due to this compartmentalization, considerable effort in inter-institutional communication is required to align the perspectives taken and methods applied, which may differ substantially as a result of conflicts of interests due to the multitude of objectives and motivations of agents involved. This is the case for, e.g., spatial planning, which is the responsibility of provincial governments and which requires extensive coordination among the provinces because of the difference in regulations. It also leads to non-uniform processes across the Austrian provinces such as, for instance, with respect to the documentation of damages incurred after past flood events. This a stakeholder described as a "chaotic" and untransparent process leading to the feeling of injustice with respect

[2] „Wir verbauen uns eine schadensfreie Zukunft".

to the disaster relief fund payouts made. As another example, the hazard zone plans developed for Austria are provided by different institutions, i.e. one for wild streams and one for other water bodies. This is lamented especially by local authorities having to utilize both if their municipality falls within the boundaries of either hazard zone plan.

Achieving a consensus among the diverging interests of the institutions and agencies involved in the Austrian FRM requires thorough debates and great coordination efforts. Naturally, this often makes for a lethargic and slow decision making process. This does not only add to the costs of these processes but it also leads to the implementation of sometimes outdated measures lagging behind scientific development and current management approaches. In addition to scientific advancements not yet being able to be realized in the actual FRM cycle due to a lack of competences or respective infrastructure, the discrepancy between science and reality can also take the form of a disassociation to an extent that renders some scientific theory inapplicable to the realities of FRM.

5. Discussion

Since the 1970s, the Austrian government has substantially increased its spending on more future-oriented FRM and broadened its portfolio of management measures (BMNT, 2018). As suggested here, however, there is a need to establish indirect FRM as a pillar within DRM – and, by extension, CRM – such that this domain is given the attention it needs and that flood events can sustainably be coped with in the future. The fact that indirect risks are currently featured in decision making processes is a testament to the high level of FRM in Austria. This means that there is awareness of the indirect effects of floods and that systemic thinking is underway. For truly holistic CRM to take hold, however, several challenges are still ahead. In the following, we discuss in more detail how to possibly overcome the barriers identified as well as which ways forward there are to take, especially with governmental institutions as decision-makers.

5.1. Closing data gaps

Our study showed that a lack of reliable data on disaster impacts impedes indirect FRM significantly (see Fig. 4, column 3). As the implementation of FRM measures requires substantial financial resources, stakeholders need data as comprehensive as possible to inform the decision of whether or not investments are realized, including the analysis of counterfactuals (e.g. events which could have happened but did not, see Woo, 2021). Therefore, greater effort is required in the documentation, analysis and modelling of the total, i.e. direct as well as indirect, damages caused by floods. Establishing a national database of loss events and associated damages (direct as well as indirect), as done in the CESARE project, is a first and vital step towards this goal. First of all, however, an agreement needs to be reached on which cost components are to be included in the assessment and how this is done, as certain effects (e.g. those on health or the environment) cannot easily be priced. Additionally, the uncertainties potentially involved in scientific data processing and modelling need to be outlined. Available macro-economic methods, integrated with past damages and estimated future impacts could help in resolving this issue.

According to estimates, climate change will most probably only take strong effect after 2050 due to inertia. Therefore, stakeholders urge that projections about flood risk and associated losses be made not only up to but also beyond 2050. Additionally, the projected losses with and without CRM measures taken should be juxtaposed in order to show the benefits of adaptation as opposed to inaction. What is integral here is that the communication of results is improved between the science community and the authorities involved in FRM as well as politicians. This includes clearly communicating the uncertainties inherently linked to such socio-economic and climate data (Leitner et al., 2020). This way, decision-makers have access to and an understanding of the most recent research results but also its limitations. In return, scientific research can benefit from knowledge about which data are important and useful to FRM actors and be shaped accordingly.

Irrespective of the quality of the data used for decision-making processes, however, learning processes and adaptive measures should play a central role especially in connection with climate-related risks, where the level of uncertainties and complexities is high. In other words, iterative FRM that builds on monitoring and evaluation processes, flexible and adjustable strategies and the consideration of multiple risks should be at the center of decision-making processes.

5.2. Promoting holistic and long-term FRM approaches

For a long-term perspective to take hold in FRM, the increase in flood risk resulting from climate change should be explicitly considered. Past research has shown that a climate change induced increase in extreme events in the future will (and already has) put significant stress on the disaster relief fund and public debt (Mochizuki et al., 2018; Schinko et al., 2017; Unterberger et al., 2019) causing also high indirect damages in many sectors. However, our and other recent studies have found that climate-sensitive decision making, i.e. CRM, is still insufficiently developed in Austria (Leitner et al., 2020; Nordbeck et al., 2019): Climate change effects, though largely uncontested by the stakeholders interviewed, are not yet being integrated in FRM planning.

Even though – or exactly because – climate change effects are foreseeable yet vague, a more holistic, pro-active and dynamic FRM becomes vital. Too often, however, measures fall too short by neglecting the spatial and temporal dependencies of floods but also the dependencies between other hazards and drivers. An example for this type of shortcoming is the misconception that a current lack of statistically proven increase of flood events is a sign of climate change not affecting riverine systems rather than the mitigative effect of, for instance, structural FRM measures (Schlögl et al., 2021). Such misconceptions, stakeholders warn, may lead to false adaptation, maladaptation or path dependencies the reversal or alteration of which, ultimately, generate high costs. How slow, gradual and expensive the processes of reversing false adaptations are, is shown by restoration or relocation projects implemented in the past.

These are often reactions to past land use, FRM decisions or previously unknown flood risks (Schindelegger, 2019) and proof that still more systemic perspectives and more dynamic management approaches (i.e. iterative FRM) need to be adopted. Seeing that the stark increase in flood damages is, amongst others, a result of increased asset accumulation in flood-prone areas (Schipper et al., 2016), there is a need for policy changes in Austria – and especially in the field of spatial planning as Austria shows one of the highest levels of land consumption in Europe (Getzner and Kadi, 2020). Stakeholders call for the enforcement of stricter zoning regulations, which would help discontinue the trend of recent decades that has led to a steady accumulation of assets in flood-prone areas.

Naturally, striking a balance between socio-economic requirements and robust and resilient flood management systems often results in considerable pressure on local authorities and spatial planners. This is especially the case in the more mountainous regions of Austria, where residential areas and building plots are scarce. Therefore, measures to preserve or create floodplains are rarely implemented as they would entail severely restricting areas which are attractive building sites (Löschner et al., 2017; Fuchs et al., 2017). Nevertheless, not applying long-term perspectives and disregarding projections on flood risks which show an increase of precipitation especially in the alpine regions of Austria (Castellarin and Pistocchi, 2012; Madsen et al., 2014) carry high risk of maladaptation and path dependencies. To avoid this, a national strategy for spatial planning in flood prone areas that considers spatial dependence could help align provincial efforts of FRM. The *River Basin and Risk Management Concept* (GE-RM) that seeks to align management projects along river catchments (BMNT, 2018) serves as a good starting point for such an undertaking on the regional level and shows that the transition to a more holistic FRM is already underway. It is also evidenced by the fact that the ecological orientation of FRM was incorporated in the National River Basin Management Plan (NGP). Indeed, more and more measures are taken which combine a broader variety of FRM measures including adding ecological components to structural measures, regulating building techniques, implementing spatial planning, etc. (Nordbeck et al., 2019).

5.3. Enhancing awareness and responsibility-taking

Another main obstacle to overcome in the Austrian FRM is a lack of awareness of flood risks. Kundzewicz et al. (2018) write that "[i]t is important to emphasize that floods constitute a hazard only when humans encroach on flood-prone areas". Thus, the public perception needs to be changed so that flood damages are no longer seen as an act of God but rather a result of human action and that the responsibility to avoid them not solely lies with the authorities. Past research found that of those countries surveyed, people's trust in public flood protection was strongest in Austria (Hanger et al., 2018). In other words, Austrians were most inclined to feel safe if their property was protected by structural measures of flood management but they were also least inclined to take private risk reduction measures. Therefore, increased efforts with regard to information campaigns are vital on, for instance, the limits of protection (i.e. residual risk), individual responsibility for risk reduction. So, too, is improved information transfer between the science community/authorities and the public. Current efforts and, by extension, current funding should, therefore, be expanded in the future for the dissemination of information. This is especially the case with pluvial floods as people are even less aware of this particular risk.

As stakeholders involved in this and past studies (Leitner et al., 2020; Thaler et al., 2020) have stated, the time frame for awareness-raising measures is small. Usually, such measures are most successful within the first three years after a flood event. In addition to promoting individual responsibility, information transfer (and how it is conducted) is vital for residents to accept and trust the decisions reached within a planning process. Local authorities reported discontent and even mistrust among residents in planning processes, which might have been prevented had communication been better as for how and why measures are being taken. Similar results were reported by Alexander et al. (2018).

5.4. Adapting financial disaster risk management instruments

Considering increasing losses expected due to climate and demographic change as well as more complex economic ties, the financial aid program for flood damages in Austria has to be adapted to be able to ensure sustainable and equitable DRR financing in the future. This means that even if the current compensation scheme (i.e. Austrian the disaster relief fund) remains in place, its payment should be tied to certain obligations[3]. These include tying them to terms and conditions which encourage private risk reduction measures (e.g. payment only for when there is proof of defense measures having been implemented), which prevent compensation for assets multiply damaged (as is already the case in certain provinces) or which discourage new settlements in high risk areas in the first place. Likewise, Leitner et al. (2020) suggested that the Austrian disaster relief fund could be reshaped to incentivize risk reduction in the private domain alongside such insurance models, "as part of a public–private partnership […], going into the direction of a disaster resilience fund" (p. 10). Similar to payments from the Austrian disaster relief funds, stakeholders suggests tying European Union Solidarity Fund (EUSF) payments, which provide relief for catastrophic losses, to proactive FRM and reduction measures to decrease the risk of maladaptation and cost traps.

Even if reshaping the current aid program would hold great benefits, we are, in fact, arguing for an entirely different mechanism for providing post-disaster relief, namely an insurance-based solution. Flood insurance programs already exist in Austria, however, as uptake is voluntary, high-risk properties or properties of low-income households are often not covered (Tesselaar et al., 2020; Hudson et al., 2019). To circumvent this problem, insurers suggested introducing a compulsory natural hazard insurance program as an annex to the current fire insurance. In addition to the benefits of comprehensive insurance coverage, greater certainty with respect to annual

[3] Suggesting a reshaping of the fund, however, is not to say that it is not a highly useful tool in financing preventive measures, emergency and recovery operations, the Austrian alarm and warning system and the restoration of public infrastructure.

public expenses and the accompanying awareness campaigns to increase member's risk awareness and engagement, also incentive functions could be fulfilled by tying payouts to private risk reduction measures and/or reducing premiums if such actions are taken. A first draft for this type of insurance was already presented by Prettenthaler and Albrecher (2009, see for a detailed analysis and additional benefits) and modelling efforts have shown the favorable effects of various insurance arrangements compared to the current compensation scheme (Unterberger et al., 2019). Mandatory natural hazard insurance has already been introduced in some European countries, such as Switzerland and Belgium. In Austria, however, it has, up to now, proven to be politically difficult to implement.

The benefits of such insurance schemes is demonstrated by a state-subsidized crop insurance offered to farming businesses by the *Hagelversicherung*. This insurance option is an important instrument for preserving agricultural structures in Austria and for incentivizing damage prevention (the latter since financial aid was no longer paid out as ad-hoc transfer but as insurance). Similarly, a natural hazard insurance could tie financial incentives to insurance premiums to reward private risk reduction, increase risk awareness and, within reason, preserve structures in areas which would otherwise fall at risk of abandonment in the future.

Introducing mandatory natural hazard insurance would require a reshaping of the Austrian disaster relief fund, so as to not counteract the implementation of an insurance scheme. Currently, the disaster relief fund functions as a direct substitute of a natural hazard insurance and leads to moral hazard effects: Individuals may avoid investing in risk reduction or purchasing insurance since financial compensation from the government is guaranteed. With mandatory insurance, damages to private assets would no longer be covered by the disaster fund. Taxes collected for the disaster relief fund could, for instance, be partly repurposed for natural disaster insurance premiums (Prettenthaler and Albrecher, 2009).

5.5. Removing institutional barriers

Given the dependencies within the system (economic or social), a starting point for more holistic FRM is to increase inter-agency communication and coordination. Although the Austrian FRM's specialization according to competences and responsibilities is, to a degree, beneficial and necessary, it also leads to barriers between institutions. These, as was criticized by stakeholders, impair the transfer of information and coordination of management measures. Exactly to this point, the UNDRR (2019) issued the following warning: "Risk is complex. While it can be practical to categorize risk so that responsibility can be delegated to different organizations, institutions or individuals, flood risk management must not be "departmentalized"." (p. V). Therefore, it is important to improve inter-agency communication and cooperation to break down these barriers and promote the coordination of measures. Thus, indirect FRM (as well as other aspects within FRM) can be prevented from being departmentalized, even though it might become more of a responsibility and concern for some institutions than for others. As was mentioned before, streamlining otherwise province-specific FRM practices and replacing sectoral thinking with systems perspective is especially important with respect to the spatially dependent nature of flood risks. This means, for instance, harmonizing land use planning protocols and standardizing documenting process of damage data and payments form the Austrian disaster relief fund to contribute to a national loss database and avoid unjust treatment of the recipients of the fund.

6. Conclusion

This study sought to determine the status of/barriers for FRM with respect to indirect risks by way of a case study of Austria. More specifically, we demonstrated (1) whether and how indirect damages are currently accounted for in the Austrian FRM, (2) which barriers are faced in their implementation and (3) which suggestions can be made for ways forward in establishing indirect FRM as well as more holistic CRM strategies mitigating indirect flood risks and climate risks. Overall, we find that awareness levels on the potential threats to public and private capital and budget are high among stakeholders and some management measures to cope with indirect flood damages are already in place. Nonetheless holistic FRM, i.e. one which takes into account direct as well as indirect damages and their respective prevention, is currently not yet sufficiently established in Austria and needs to be better embedded within sustainable and development planning processes in the future.

As possible next steps forward we suggested that (1) analyses of flood damages must go beyond direct damages and should explicitly include indirect ones. (2) FRM options need to be designed which adopt long-term views and holistic approaches, i.e. which take into account future changes in both the frequency of hazard events and the magnitude of anticipated losses also with regard to indirect risks. A lack of data has proven the greatest obstacle to accomplish this. Thus, more effort is needed in estimating or collecting data on indirect damages as data issues prevent stakeholders from implementing indirect FRM measures. These efforts should be institutionalized to help build up an inventory of indirect damages, which can then be used not only for risk awareness and model building but also for identifying how and where indirect damages emerge. The same holds true for data on and projections of climate change effects which should feed into holistic, iterative FRM approaches that favor flexible decision-making processes. Increased data collection, however, should not discourage the adoption of dynamic and adjustable management approaches, which are at the center of iterative FRM processes.

Additionally, (3) awareness levels of flood risks in the public should be raised and responsibility sharing be enhanced, which might go hand in hand with (5) adapted financial aid schemes promoting private risk-reduction measures. We especially see potential in insurance-based approaches to reduce pressure on public budgets and increase private risk reduction. Lastly (6), inter-agency communication and cooperation needs to be improved, which will be the key to successfully reduce indirect risk due to the interrelationships of various systems such as the physical, natural as well as social and economic one. Different modelling approaches dealing with such specific systems and corresponding risks are already (being) developed, e.g. in climate science, ecology, sociology or economics, but their interaction and links still need to be established in the future. This can be, for example, achieved either through soft or hard linking wherever possible.

The design of our study is subject to certain limitations. These include a possible bias in the scope of stakeholders interviewed, which might lead to certain indirect risks to not have been accounted for (e.g. private households' representatives or interest groups have not been interviewed, despite possible indirect risks to private households via the labor market). Additionally, a network analysis of the Austrian FRM apparatus could form the basis for future studies since it did not fall within the scope of this study. Since the connectedness within the system lies at the core of indirect FRM, this type of analysis could yield beneficial insights. Lastly, it is hardly surprising that stakeholders' awareness levels for indirect effects is high since the topic of our interview was clear when stakeholders were contacted. Thus, it is only logical – and to be held in mind – that only stakeholders to whom the issue of indirect effect anyways is of interest and relevance agreed to an interview.

We acknowledge that the context of the case study is very specific to Austria. Thus, inferences about other countries and regions need to be drawn carefully. Nevertheless, we argue that our results are insightful to other countries, especially if their economic structures are similar and their FRM apparatus is equally well developed. Irrespective of country, region, economic structure and level of development of FRM, we see a general need for a more holistic view on CRM, such as we present here. This means adopting future-oriented approaches in CRM that move beyond direct risks to also include indirect ones. Likewise, cooperation efforts, in general, need to be encouraged, not only national but also across borders and should be a central topic in future research.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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