Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	MacroMode
Langtitel:	Macroeconomic Modelling of Indirect Risks for Climate Risk Management
Zitiervorschlag:	Hochrainer-Stigler, S., Poledna, S., Knittel, N., Reiter, K. and Bachner, G. 2022. Macroeconomic Modelling of Indirect Risks for Climate Risk Management. Final Report.
Programm inkl. Jahr:	ACRP – 11th Call, 2019
Dauer:	1.11.2019 bis 30.06.2022
KoordinatorIn/ ProjekteinreicherIn:	International Institute for Applied Systems Analysis (IIASA)
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Projekt- und KooperationspartnerIn	University of Graz, Styria
Schlagwörter:	Flooding, Indirect Risk, Multi-Modell Approach, Input-Output Modelling, Computable General Equilibrium Modelling, Agent-Based Modelling, Risk-Layering, Participatory Approach
Projektgesamtkosten:	249.900,00 €
Fördersumme:	249.900,00 €
Klimafonds-Nr:	KR18AC0K14602
Erstellt am:	29.09.2022

B) Projektübersicht

1 Kurzfassung

Indirekte Risiken aufgrund von Naturkatastrophen, wie z.B. Verluste durch Betriebsunterbrechungen oder eine höhere Verschuldung, und die Auswirkungen des Klimawandels sind für viele Risikoträger auf der ganzen Welt, einschließlich des privaten Sektors und Regierungen, ein wachsendes Anliegen. Das Ziel von MacroMode war es, Risikomanagementoptionen zu identifizieren, zu quantifizieren und zu bewerten, die die indirekten Risiken von extremen Hochwassergefahren für öffentliche und private Akteure in Österreich heute und in der Zukunft verringern können. Um dieses Ziel zu erreichen, wurden drei hochdetaillierte gesamtwirtschaftliche Modellierungsansätze angewandt, nämlich ein Input-Output-Modell (IO), ein angewandtes allgemeines Gleichgewichtsmodell (CGE) und ein agentenbasierter Modellansatz. Darüber hinaus wurden diese Modelle in einen iterativen Stakeholder-Prozess eingebettet, um Bedürfnisse und Prioritäten sowie mögliche Konflikte aufgrund unterschiedlicher Werturteile unter den Stakeholdern zu erörtern, um Vertrauen zu stärken und einen offenen Dialog zwischen den Stakeholdern zu ermöglichen. Die Ergebnisse aus diesem Stakeholderprozess wurden, soweit möglich, verwendet um Modellannahmen dementsprechend anzupassen.

Unsere Untersuchungen zeigten, dass es derzeit in Österreich nur wenige Managementinstrumente zur Bewältigung indirekter Hochwasserrisiken gibt. Indirekte Hochwasserrisiken werden jedoch von den Stakeholdern als erhebliche Belastung sowohl für den/die Einzelne*n als auch für die nationale Ebene erkannt. Einer der Hauptgründe dafür, dass Managementmaßnahmen für indirekte Risiken noch nicht oder nur schwer umgesetzt werden können, sind allem voran die fehlenden Daten zu den indirekten Kosten von Hochwasser. Dazu gehören sowohl Daten über vergangene Ereignisse als auch verlässliche Vorhersagen über die künftige Entwicklung der Kosten unter Berücksichtigung des Klimawandels. Da solche Daten nicht ohne weiteres verfügbar sind und Modellierungen mit inhärenten Unsicherheiten behaftet sind, zögern Stakeholder, kostspielige Maßnahmen einzuführen, ohne diese Entscheidungen auf verlässliche indirekte Schadensdaten stützen zu können. Zudem müssen politische Optionen entwickelt werden, die die gesamten, d.h. sowohl direkten als auch indirekten Schäden von Hochwasser berücksichtigen und eine längerfristige Perspektive einnehmen. Als ersten Schritt empfehlen wir, Hochwasserrisikomanagement indirekter Risiken als eigene Säule innerhalb des Katastrophenrisikomanagements einzuführen, die in Kombination mit Klimawandel-Anpassungsstrategien ein effektives und ganzheitliches Klimarisikomanagement bilden kann.

Für die drei Modellierungsansätze wurde ein Schadensszenariengenerator entwickelt, um großflächige Hochwasserereignisse und die damit verbundenen Schäden entsprechend der räumlichen Verteilung von Kapital, das im Besitz von Nicht-Finanz- und Finanzunternehmen sowie von staatlichen Stellen ist, innerhalb

Österreichs abzuschätzen. Die Ergebnisse des IO-Modells können besonders gut als Orientierung für die Identifizierung von Schlüsselsektoren während der Wiederaufbauphase herangezogen werden. In fast allen Szenarien erwies sich hier der Transportsektor als besonders wichtig. Interessanterweise kann sich die Priorität zwischen den Sektoren bei unterschiedlichen Schweregraden des Ereignisses ändern, da jedes Ereignis unterschiedliche Expositionsniveaus und sektorale Verlustverteilungen aufweist. Die Ergebnisse des ABM zeigten, dass extreme Katastrophen sowohl unmittelbar nach dem Ereignis als auch langfristig starke negative Auswirkungen auf die Wirtschaft haben. Das CGE Modell zeigte, unter anderem, unterschiedliche Verteilungseffekte für verschiedene Einkommensgruppen und langfristige Wohlstandsverluste.

Zur Bewältigung dieser Risiken und möglicher langfristiger negativer Entwicklungen wurden mehrere Managementoptionen identifiziert. Dazu zählen die Entwicklung einer Entschädigungsregelung, die das Einkommensniveau bei der Entschädigung für Kapitalverluste berücksichtigt. Eine weitere Option ist die Verringerung des Fachkräftemangels, vor allem in den Sektoren, die in der Zeit nach der Katastrophe von Bedeutung sind, wie z. B. im Baugewerbe und in der Maschinenproduktion. Durch die Deckung des Bedarfs an Arbeitskräften wird der Wiederaufbau erleichtert, was zu einer Verringerung des wirtschaftlichen Gesamtschadens führen würde. Durch die Umsetzung dieser beiden Managementoptionen können die oben erwähnten Verteilungseffekte sowie Wohlfahrtsverluste bekämpft werden. Darüber hinaus zeigen die Modellergebnisse eine deutliche Verbesserung der Schulden- und der Arbeitslosenquote, wenn Schuldenfinanzierung und staatliche Mittel für den Wiederaufbau leichter verfügbar gemacht werden.

Basierend auf den obigen Ergebnisse befürworten wir einen integrierten und iterativen Rahmen für das direkte und indirekte Risikomanagement, der idealerweise in einen umfassenden partizipativen Prozess eingebettet sein sollte. Darüber hinaus empfehlen wir die Anwendung eines Systemansatzes, der eine ganzheitliche Betrachtung verschiedener Perspektiven ermöglicht, einschließlich solcher, die nicht direkt mit dem Katastrophenrisikomanagement in Verbindung stehen, sondern sich allgemein auf Entwicklungsaspekte konzentrieren. Derart integrative Ansätze für indirektes Risikomanagement können gleich mehrfachen Nutzen für die Gesellschaft erzielen. Darüber hinaus sind aufgrund der sich verändernden sozioökonomischen Bedingungen adaptive und iterative Prozesse für die Bewertung indirekter Risiken erforderlich. Ein toolboxbasierter Ansatz, der in einen solchen Prozess eingebettet ist, ist hier besonders vielversprechend, da er es ermöglichen würde, Methoden, Modelle und Ansätze auf eine Art und Weise zu verknüpfen, die die komplexe Natur einer solchen Analyse hervorhebt und somit die Existenz mehrerer Ansatzpunkte für das Management indirekter Risiken betont.

2 Executive Summary

Indirect risks due to natural disasters, such as losses due to business interruption or increased debt, and climate change impacts are a growing concern for many risk bearers around the world including the private sector and governments. Particularly in highly developed countries, there has been a recent shift in disaster risk management with respect to indirect losses to answer the question of how indirect losses due to natural hazard risks can be decreased. Risk-based approaches are recommended in many fields of activity in the Austrian National Climate Change Adaptation Strategy, most notably in the field of "Catastrophe Management". However, traditional risk management still focuses heavily on the direct effects of natural disasters. While direct risk management also reduces the chances of indirect risks, as the latter emerges in association with the former, indirect effects are particularly important for economies characterized by a high degree of specialization and strong inter-sectoral linkages, such as is the case for the Austrian economy. The aim of MacroMode was to identify, quantify and evaluate risk management options that can decrease indirect risks from extreme flood hazards for public and private stakeholders in Austria today and in the future. To meet this objective, three highly detailed economy-wide modelling approaches were applied, namely an Input-Output modelling (IO), Computable General Equilibrium (CGE) Modelling and Agent Based Modelling (ABM) approach. Furthermore, these models were embedded within an iterative stakeholder process in which priority needs, model assumptions, possible frictions due to different value judgments among stakeholders were discussed and which aimed at increasing trust and enabling an open dialogue between stakeholders.

Currently, only few management instruments are in place to tackle indirect flood risks in Austria. Nevertheless, stakeholders recognize indirect flood risks as a substantial financial burden on both the individual and the national level. Management instruments currently in use include privately offered, voluntary insurance products with limited cover sums, cost-benefit analysis which provide a qualitative description of loss of value added in the flood-affected region, critical infrastructure protection strategies as well as the Austrian disaster relief funds. One of the main reasons identified why management measures for indirect risks are not yet implemented or are difficult to implement is a lack of data on the indirect costs of floods. This includes data for past events as well as reliable predictions for the future development of costs that take into account climate change. Since such data is not readily available and modellings are tied to intrinsic uncertainties, stakeholders are reluctant to implement costly measures without being able to base these decisions on reliable indirect damage data. This is an issue of great concern among stakeholders as it impedes indirect Flood Risk Management (FRM). Based on these challenges, we propose to establish a more holistic FRM concept which takes into account the spatial and temporal dependencies of floods and indirect risks. Especially policy options need to be developed, which factor in the total i.e. direct as well as indirect damages, of floods and that adopt a more long-term perspective. As a first step, we recommend introducing indirect FRM as a separate pillar within Disaster Risk Management, which can form effective and holistic climate risk management in combination with climate change adaptation

For the three modeling approaches, a loss scenario generator was created to estimate large-scale flood events and associated losses according to the spatial distribution of capital owned by non-financial firms, financial firms, and government entities. The results were used as inputs to the three modeling approaches. We found that the IO model results could be used as a guide for identifying key sectors during the recovery phase. In almost all scenarios, the transportation sector was found to be particularly important. Interestingly, the priority between sectors may change for different events, as each event has different exposure levels and sectoral loss distributions. The ABM has shown that extreme disasters have very negative economic impacts both immediately after the event and in the long run. Using the CGE model important distributional effects in terms of gains and losses for different income groups and long lasting welfare effects were found.

To address these risks and possible long-term negative developments, we identified several management options, including the development of a compensation scheme that takes income levels into account when compensating for capital losses. Another option is to reduce the shortage of skilled labor, especially in sectors that are important in the post-disaster period, such as construction and machinery production. Meeting labor needs will facilitate reconstruction, which would lead to a reduction in overall economic damage. Implementing these two management options can combat the distributional effects mentioned above as well as welfare losses. In addition, the model results show a significant improvement in the debt ratio and unemployment rate when debt financing and government funds are made more readily available for reconstruction. Based on the above results, we propose an integrated and iterative framework for direct and indirect risk management, ideally embedded in a comprehensive participatory process. Furthermore we suggest to use a systems approach that enables an integrated appraisal from various perspective, including those not directly related to disaster risk management but focused on development issues more generally. This opens the possibility of a multiple benefits approach to indirect risk management strategies. In addition, changing socioeconomic conditions require adaptive and iterative processes for indirect risk assessment. A toolbox-based approach embedded in such a process is a promising way forward, as it would allow methods, models, and approaches to be linked in a way that highlights the complex nature of such an analysis and thus emphasizes the existence of multiple entry points for indirect risk management.

3 Hintergrund und Zielsetzung

Risks due to natural disasters and climate change impacts are a growing concern for many risk bearers around the world, including the private sector as well as governments. Part of the paradigm shift calling for a more proactive and risk-based approach can be explained by the fact that disaster risk has increasingly been recognized as a major challenge to economic growth and overall societal wellbeing in both developing and developed regions of the world. Also, in the Austrian National Climate Change Adaptation Strategy risk-based approaches are recommended in many activity fields, most notably in catastrophe management. Especially for highly developed countries, a shift in the management perspective for disaster risk can be observed in regards to direct and indirect losses. Indirect losses are the flow-on effects from direct losses, such as transport disruptions or business interruptions and can be larger than the direct losses. This is particularly the case for industrialized countries, as they are characterized by a high degree of specialization and strong inter-sectoral linkages. Hence, the economy-wide view is becoming more prominent, including also the indirect risks that emerge from economy-wide linkages (thus capturing the total of direct and indirect effects). To tackle these indirect risks, the government is often, at least implicitly, seen responsible for keeping them as small as possible and/or to re-distribute them.

Given this shift to an economy-wide perspective, also a significant change in risk management perspectives needs to be undertaken and the question needs to be addressed of how indirect risks from natural hazards can be decreased within highly interlinked and complex systems such as the economy of a country like Austria. This question has so far not been addressed in the research domain; and neither its application aspects. In MacroMode, three overarching objectives were identified: The first and main objective of MacroMode was to identify, quantify and evaluate climate risk management options that can decrease indirect risks from flood hazards today and in the future in Austria. The second objective was to shed light on fundamental model uncertainties in order to provide more robust results by using three state of the art macro-economic modeling approaches for economic consequences of flood events. The third objective was to collaborate with key decision makers and stakeholders to develop policy compatible ways forward on how to tackle indirect risks due to flood events in Austria now and in the future.

In WP1, we estimated risk-based flood scenarios using a new Copula approach at the country level and assigned the corresponding losses to the different sectors in an unprecedented level of detail. In fact, all existing businesses in Austria were explicitly included and associated with flood vulnerability. Regarding the future impacts of climate change, we used information from previous studies and focused on the A1B and SSP2 scenarios, which we linked to a so-called risk layer approach. Finally, a loss scenario generator was created and used as input to WP2. In addition, a risk layer approach originally developed in the insurance industry was used to develop a new approach for indirect risks focusing on interconnectedness as a key element for risk management. In addition, using a newly developed systems perspective, a stakeholder mapping exercise was conducted to identify stakeholders for whom indirect risk management could potentially be particularly important and to identify their perceptions and priority needs (as views on the objectives as well as priority needs for indirect risk management could differ among these stakeholders due to flood events).

In WP2, the input of the damage scenario generator from WP1 was used for estimating indirect impacts due to direct damages caused by flood events. The models used are among the most detailed currently available in the world for a given country. Considerable effort has gone into calibrating the models and modeling the macroeconomic dimensions in as much detail as possible, based on a stochastic set of damage events from large-scale flooding. By comparing the different models, including input-output modeling, computable general equilibrium modeling, and agent-based modeling, the different results were compared in terms of modeling philosophy and underlying assumptions, as well as strengths and weaknesses with respect to different dimensions, including the temporal dimension and the representation of the dynamics of sectors after disaster events. The results were again presented and discussed in close collaboration with the identified stakeholders within WP1 and used for WP3.

WP3 tested the specific risk management options and their feasibility. The risk level approach from WP1 was adopted using the modeling results from WP2 and discussed with key stakeholders through a participatory and integrated assessment. Importantly, the link between disaster risk management and development dimensions was extended by exploring specific strategies that are also beneficial for other reasons, such as those related to economic growth or fiscal and financial stability. A multi-stakeholder workshop was held to assess and evaluate the various strategies identified through a dialogue with stakeholders to create a policy compromise package. Finally, the results were used in a broader framework to propose new ways to manage the indirect risk of natural disasters through a policy and regulatory process that considers both direct and indirect impacts.

Our research results provide a new and comprehensive overview of the status of flood risk and indirect impacts as well as flood management in Austria at the national and local levels. The insights we have gained should also be useful for countries around the world, especially those with highly interconnected sectors. Current policies and tools are limited in their effectiveness against indirect flood risks, but can be adapted to go beyond these limits. More importantly, such tools can also be useful for other, non-disaster reasons and therefore provide benefits even when disasters do not occur. Future research, however, needs to focus on how to implement the necessary changes, as some institutions are not yet able to address the unique challenges of indirect risks.

4 Projektinhalt und Ergebnisse

WP1: Estimating and managing current and future costs due to extreme flood events using copulas and risk layering

The first goal and task (Task 1.1.) in WP1 was to generate very detailed probabilistic scenarios for the direct costs of extreme flood events for today and the future for Austria. This so-called damage scenario generator was used as input for WP2 and WP3. Afterwards, a risk catalog (Task 1.2) for the indirect risk should be developed, including the possibility of different potential risk management options. Finally, a stakeholder mapping for indirect risk management should be created and how indirect risk can propagate or cascade through the system (Task 1.3).

The challenge addressed in Task 1.1 was to avoid underestimating losses for extremes that may cause systemic risk and/or large indirect risks. This was done using what is known as a copula approach. The approach is particularly useful because it allows analysis of large-scale extreme events at the country level (Hochrainer-Stigler et al. 2018) which is an essential prerequisite for a probabilistic macroeconomic analysis. We used information from two previous projects funded under the Austrian Climate Research Programme (ACRP), namely, COIN and Public Adaptation to Climate Change (PACINAS), which provide probabilistic information on the country level regarding losses today and in the future. This includes grid-scale (25x25 km) loss information for the SRES A1B scenario (Nakicenovic and Swart 2000), which is used as the input to the copula approach in Schinko et al. (2016). The data as well as copula approach was used to build up a flood scenario damage generator, which is needed to estimate indirect risks in a probabilistic fashion.

More specifically, the dependent nature of such risks needs to be explicitly considered in the analysis of large-scale natural disasters. So-called copula approaches are currently considered best suited to account for the tail-dependent behavior of such events, e.g., strong correlation of losses between different regions in the case of large-scale hazard events (Jongman et al. 2014). Otherwise, losses may be severely underestimated and risk management instruments are likely to fail especially in cases where they are needed the most (see Hochrainer-Stigler et al. 2014). Additionally, it is now argued in the literature that classic risk measures that focus on the central distribution of impacts (e.g. average losses) used for informing risk management strategies have to be adapted to take the special nature of large-scale risks explicitly into account (Hochrainer-Stigler et al. 2020). For example, in Schinko et al. (2016) country level average annual losses due to flood events in Austria were estimated to be around 250 million Euro, however, a 500 year flood event would cause losses of about 15 billion Euros. As our work specifically looks at very extreme events, these two considerations, tail dependence and risk-based assessment, had be taken explicitly into account. We used the data and methods as described in Schinko et al. (2016) and Mochizuki et al. (2018) which included tail dependence in their analysis to calculate losses for various return periods for the specific case of Austria as well as very extreme large scale disruptions, which we called Armageddon Scenarios (because of their extreme high losses) based on different assumptions (Table 1 and Table 2).

Table 1: Current and future losses (in constant bn 2015 Euros) for different return periods. Source: Based on Mochizuki et al. (2018); Schinko et al. (2016)

	Return periods						
Time	**20**	**50**	**100**	**250**	**500**	**1000**	**AAL**
2015	0.933	2.878	7.749	12.797	15.553	17.349	0.258
2030	1.309	3.940	10.724	17.572	20.812	23.741	0.764
2050	1.909	5.809	15.468	24.911	29.584	33.814	1.101

Table 2: Selected extreme ("Armageddon") scenarios

	% of capital stock destroyed	**characterization**
Armageddon Scenario I	3	1000-year event in all basins simultaneously
Armageddon Scenario II	5	Selected Scenario for Interest
Armageddon Scenario III	17	Half of total exposed assets destroyed
Armageddon Scenario IV	34	Total of total exposed assets destroyed

The next and even more important challenge was to allocate the losses to the very local level of the respective actors. In other words, the second major challenge in this task was to relate the losses to individuals on a very fine-grained scale. After some tests with different exposure databases (e.g. CORINA), we finally used the so-called SABINA database, which includes all financial statements of all Austrian companies that are legally required to file such a statement (see http://www.bvdinfo.com/en-gb/our-products/company-information/national-products/sabina for further information). In addition, we were able to geographically assign the location of all companies. We were therefore able to determine the distribution of losses across all sectors by overlaying flood hazard zone maps based on the highly detailed HORA zoning system with the spatial distribution of capital by institutional and industrial sectors, which was available for all facilities in Austria (a unique feature). We then allocated losses to all 64 industrial sectors according to the spatial distribution of capital from non-financial, financial, and government entities across these sectors. As a final result, we were able to probabilistically distribute large-scale flood losses, as shown in Tables 1 and 2 above, on a very granular scale and use this as input to Working Groups 2 and 3. We conclude that the most modern approaches to climate risk management of direct risks use probabilistic approaches (IPCC, 2012) and the assessment and management of indirect risks within complex systems (such as country-level economies) should therefore be conducted in the same way (see WP3). Depending on the impact of a flood event and the corresponding losses among heterogeneous actors, different indirect effects arise, as discussed in WP2. Due to lack of information on the future economic structure, changes in risk due to climate change are given by changes in the return period compared to the base case (Table

1). The results were used in a manuscript currently under review in Risk Analysis (Bachner et al. 2022).

Related to Task 1.2 and the risk catalogue, we linked a system perspective with a risk-layering approach against indirect risk. Our starting point was the insurance perspective, where risk stratification is a classical approach. However, as our literature review revealed, the concept has been adopted in numerous other disciplines, albeit often in a less sophisticated form. In addition to the similarity in the use of the concept of risk stratification, i.e., the identification of different levels of risk, the applications of the concept in different disciplines are also similar in that different treatment or intervention strategies are developed and/or applied for them. This means that each risk factor requires its own management method and officer. We limit ourselves here to the question of how risk-layering can be adapted to indirect effects in the context of disaster risk management of natural hazards.

Risk-layering usually requires the quantification of risk, ideally in the form of a loss distribution, which relates losses to probabilities and which forms a natural linkage to risk-layering. In contrast to direct risk, where only the elements exposed to natural hazards need to be looked at, the hazards' effects experienced beyond these areas and elements must be considered when assessing indirect risk (Naqvi et al. 2020). To achieve this, a systems perspective is beneficial and, in this case, we suggest defining a system to be a set of interconnected elements within a defined system boundary (Handmer et al. 2021). The advantage of this definition is, firstly, that it creates clear borders of what a system comprises and what it does not. Secondly, its emphasis lies on the elements of the system that are the reason for indirect effects that ripple through the system. Thirdly, it focuses on the connection between elements necessary for indirect effects to be produced. Note that the system boundary may be different depending on the decision maker in question, that is boundaries differ for insurance providers (for example, exposed assets at risk), a finance ministry (for example, all economic actors of the country), or global policy makers (for example, people, assets, other ecological entities, and so on).

For natural hazards, the assessment of asset losses usually only considers elements that are exposed to this particular hazard (for example, the system only includes elements that are exposed to risk) and the corresponding risk-layer only addresses these elements (Grossi and Kunreuther 2005). For indirect risks, however, additional elements that can be affected through different transition channels have to be included. For example, while the system boundary for insurance is only the assets that can be damaged due to natural hazards, the economic consequences may include all elements (for example, households, firms, banks) indirectly affected due to the connectedness among the elements. Hence, defining clear system boundaries separately for risk-layering for indirect risks and for direct risks is essential as they might differ substantially (Naqvi et al. 2020).

Following the classic definition of risk being a function of the hazard, exposure, and vulnerability (IPCC 2012), there is no direct risk without vulnerability of the elements in a system. Hence, if the elements within a system are not potentially able to fail, there are also no indirect risks. Thus, indirect risks can only emerge in the presence of direct risks. As risk-layering for direct risk only includes elements at risk, it can be used as an input for risk-layering for indirect ones, where the system boundary for direct risk is usually a subset of the system boundary for indirect risk. In other words, the elements that can fail (that is, experience losses) are also part of the elements that will trigger indirect effects, including consequences outside the system element's definition for direct risk. However, if there is no connectedness between the elements in the system, there is also no risk of indirect effects. Consequently, system boundaries, the elements in the system and their possibility to fail, as well as the connection between the system elements are key ingredients for an indirect risk-layer approach.

How and why individual failures can cascade through a system are questions that are at the heart of systemic risk research. Many measures have been suggested for assessing elements in the system that are, from a system perspective, either too big to fail, too interconnected to fail, or too important to fail, and so on (see Hochrainer-Stigler et al. 2020 for an overview). Irrespective of how different these measures are, the connectedness between the individual elements in the system lies at the center of most of them (Poledna et al. 2017). Therefore, we argue that the connectedness of the system elements should be a key feature for a risk-layer approach for indirect risk. In more detail, similar to probability changes and corresponding loss levels in the risk-layer approach for direct risk, the increase in connectedness and its cause for increases in indirect loss levels can be used. This allows for the adaption of the risk-layer concept for indirect risk (Figure 1).

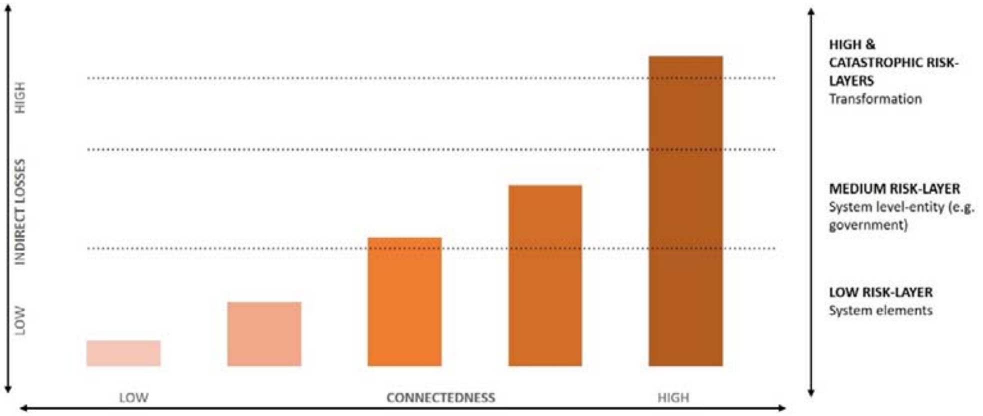

Figure 1: Risk-layers and associated connectedness, loss levels, and management options

The term connectedness is ambiguous but serves the purpose here as, indeed, it can be defined and assessed by different measures, such as copulas (for example, strength of connection), DebtRank (for example, centrality of connected elements), proportion of total elements affected, and so on. The measure used ultimately depends on the research question at hand and, therefore, must be chosen case specific (for possible measures of connectedness we refer to Hochrainer-Stigler et al. 2020). For studying a real-world system, usually the connectedness is modelled and calibrated based on empirical data. Different methods exist in that regard including econometric approaches, CGEs (Computable General Equilibrium), as well as ABMs (Agent-Based Modeling) (see for a review Botzen et al. 2019). We discuss in WP2 and WP3 practical ways forward on how to connect direct risk-layers with indirect risk-layering using CGE and ABMs following our suggested ideas (for other approaches see Botzen et al. 2019). The results were published in the International Journal of Disaster Risk Science (Hochrainer-Stigler et al. and Reiter 2021).

Finally, within WP1 and related to Task 1.3 and the stakeholder engagement, we included key stakeholders in the Austrian FRM cycle in the project from the very beginning (see Methodology section for how stakeholder communication took place). Figure 2 (stakeholders interviewed are indicated in bold) shows the map of the stakeholder landscape of the Austrian FRM apparatus produced from the interviews including the relationships among the stakeholders. 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 the different steps along the disaster management cycle, i.e. disaster prevention, disaster preparedness, disaster management and recovery, and we follow this approach here as well. A detailed content analysis was performed for all interviews conducted with stakeholders and institutions but is omitted here due to space constraints. The results are published in the Climate Risk Management journal (Reiter et al. 2022). The most important results for the direct and indirect risk management and possible instruments will be presented in the next section. Summarizing, Task 1.1 provided an input to the three modelling approaches in WP2, Task 1.2 determined possible risk strategies against indirect risks and used within Task 3.1, and Task 1.3 was used as an input for the further stakeholder interaction including the workshop set-up for Task 3.2.

Milestones:

- Development of a copula-based country flood risk model with highly detailed information of distribution of losses according to economic sectors
- Development of an indirect risk-layer approach for risk management
- Development of a stakeholder map and instruments available in Austria for indirect risk management.

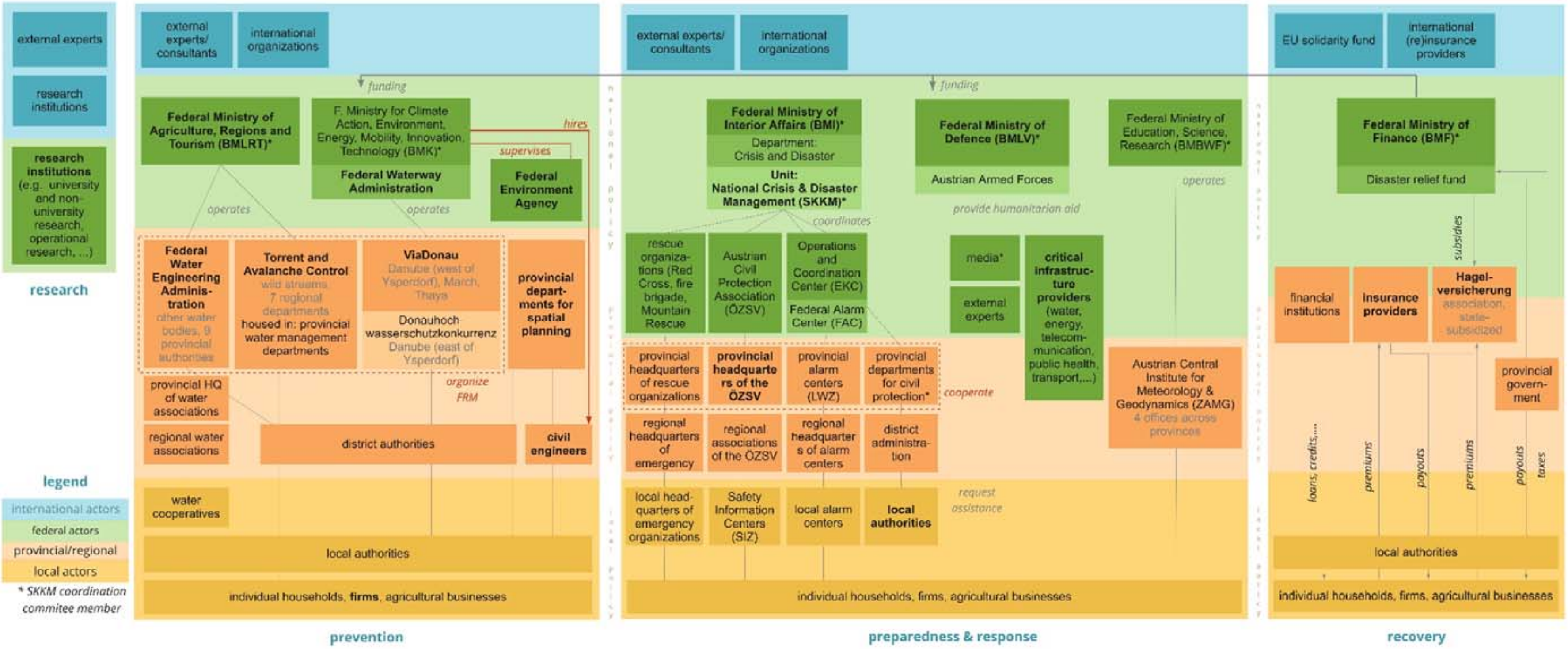

Figure 2: Key Stakeholders for indirect flood risk management in Austria. Clusters represent the field of disaster management stakeholders' (main) competences fall within, arrows explain relationship and responsibilities within the stakeholder network.

WP2: Assessment of indirect effects of flood events on the country level from a multi-model approach

WP 2 focused on different modelling approaches to estimate the indirect effects associated with flood damages in Austria. In Task 2.1 (Calibration and model consistency) three macroeconomic models (IO, CGE, ABM) were set up and linked with the damage scenario generator from WP1. Then, in Task 2.2 (Modelling Indirect Effects using a Multi-Model Approach), the indirect effects were calculated, using the three macroeconomic models. To cover a comprehensive range of possible damage materializations over time, we ran many scenarios from the stochastic damage scenario generator. This task produced results on the risks for different sectors and agents in Austria at a fine-grained level (64 sectors, multiple private households, government), under a policy-as-usual scenario. In Task 2.3 a model comparison was performed and weaknesses and strengths of the different approaches were identified and used as an input for WP 3. Regarding Task 2.1 and the calibration of the models we refer to section 6 on the methodology. Here, we focus on a selection of results from Task 2.2. The main findings and conclusions from the multi-model comparison performed in Task 2.3 will be presented in section 5. For a more comprehensive overview of results from WP2, we refer to the published report on modelling results (Bachner et al. 2022). The inter-model comparison using the produced results in WP2 were submitted and accepted (under revision) in the Risk Analysis journal.

The Input-Output (IO) modelling approach has some benefits from its relative simplicity. In fact IO models offer linearity as well as a simple way of outlining inter-industry linkages and demand structures, usually by imposing specific structural constraints. Furthermore, the empirical construction of IO datasets is supported in many countries through the development of industry classification standards such as ISIC, JSIC and NACE which is used here as well. As data basis we used the 2015 IO-table issued by Statistics Austria. The number of industry sectors, was n=62 (according to the CPA-classification of products by activity from EUROSTAT with 64 categories - the last one was void and L67 and L68 were collapsed to L). Note, the element Z(i,j) of matrix Z usually used in I-O models contains the total payments industry sector i has paid to industry sector j within the reported year. Using the matrix L, one may calculate the needed relative change of the input j given that the output i changes by 1 percent. Denoting this percentage by Cij, one may visualize this 62 by 62 matrix in a square scheme, where the size of the element at position i,j is proportional to Cij (see Figure 3 for a visual representation).

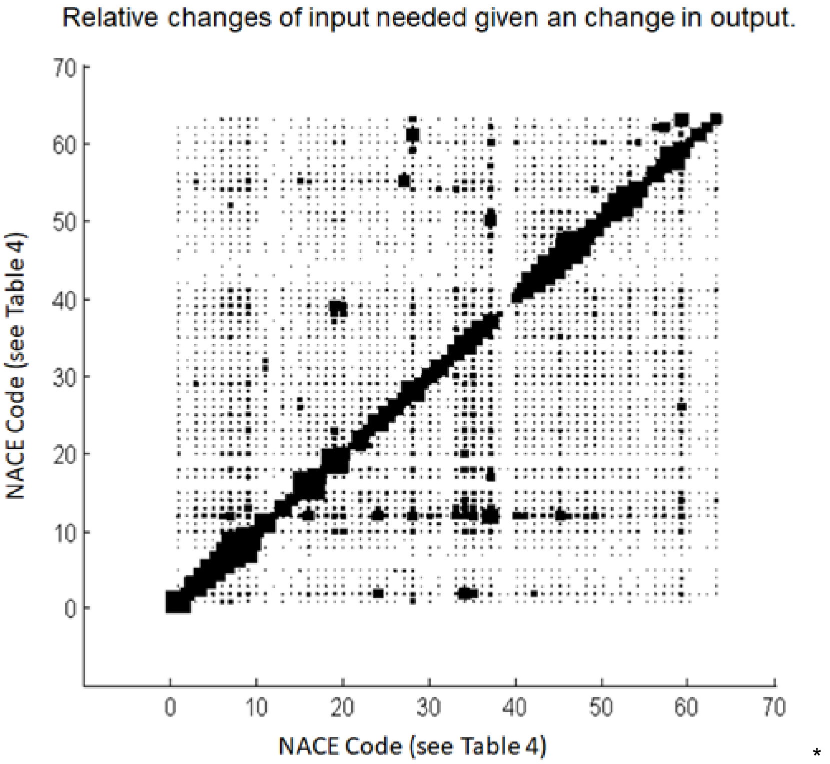

Figure 3: Relative change of the input j (y axis) given that the output i (x axis) changes by 1 percent.

In order relate the possible losses in stock to the flow values of an IO-model, we assumed that all losses will be compensated within just one year. That is, the necessary output is increased by the money value of the losses in the respective scenario. In other words, demand is increased according to the relative losses in the specific sectors based on the damage scenario generator and we look at increased input needed due to this increased demand. The one-year recovery might seem as too short, but the relative necessary increases in input calculated below may be halved if the recovery time is extended to two years. Conversely, the IO-model's output can be used to detect bottlenecks, i.e. by how much a sector's output would need to increase for compensating the damage. It is especially interesting to see that the different exposure levels which are dependent on the flooded area (based on the Zoning system) have strong impacts on the distribution of increases in the sector rather than the magnitude. In other words, for input output modelling the exposure changes for the different sectors due to different flood impacts may be of more importance for decision making than the absolute effects of the disasters.

Turning to the results of the computable general equilibrium (CGE) model, we can structure the macroeconomic effects into two channels. First, the effects that originate from damages to the sectoral capital stocks and second, the effects that are triggered by reconstruction activities. The ultimate outcome is the combined and interacting effect of these two channels. Economy-wide effects can be measured as changes in GDP and welfare. We start the analysis of our results at the point of system intervention, i.e. the capital market in 2015 (t=1). From the damage channel we expect capital rents to be higher than in the baseline scenario, since the “remaining” capital of a sector (the fractions that are not destroyed) is getting scarce. However, as capital is sector specific, capital rents can also decrease due to excess supply pressures of capital in sectors which are not that severely affected by the flood itself, but via reduced general economic activity/demand that occurs due to reduced economy-wide income after the flood event. Additionally, from the reconstruction channel we expect that the capital stock of those sectors, which are needed for reconstruction activities, increase in their valuation and thus respective capital rents to increase. For sectors which are needed less – in particular those sectors that provide consumption goods and services – capital rents are expected to decline as demand for consumption is crowded out to finance reconstruction investment. To summarize, the damage channel puts an upward pressure on capital rents due to scarcity, whereas the reconstruction channel puts a downward pressure to average capital rents due to lower demand.

Due to the large amount of output of the CGE model we refer to Bachner et al. (2022) for the full details. A summary of results is presented in Figure 4, which shows the change in the average capital rent, wage rates, nominal GDP (including relative price effects) and real GDP (at constant prices) for five damage scenarios ranging from a 1/20-year event to a scenario with 5% destruction of the economy-wide capital stock. Looking at 2015, we observe that for the high impact events average capital rents are higher than in the baseline, with the damage channel dominating. Only for the scenarios 1/20 and 1/100 the reconstruction channel dominates, which leads to slightly lower average capital rents in the year of the flood. In the post-event years (starting with 2016), we see that in all scenarios average capital rents are above baseline levels. This is because reconstruction investments also crowd out other generic investments and, thus, the pre-event capital stock is not fully re-established after the reconstruction phase. Reconstruction is assumed to take place only in the year of the event. Hence, what dominates in the following periods is the damage-channel which leaves the economy with a smaller capital stock and thus higher rents due to scarcity. This effect is getting weaker over time since the speed of capital accumulation increases after the event due to a redistribution of income towards households with higher investment (savings) rates, and thus the capital stock grows stronger than in the baseline.

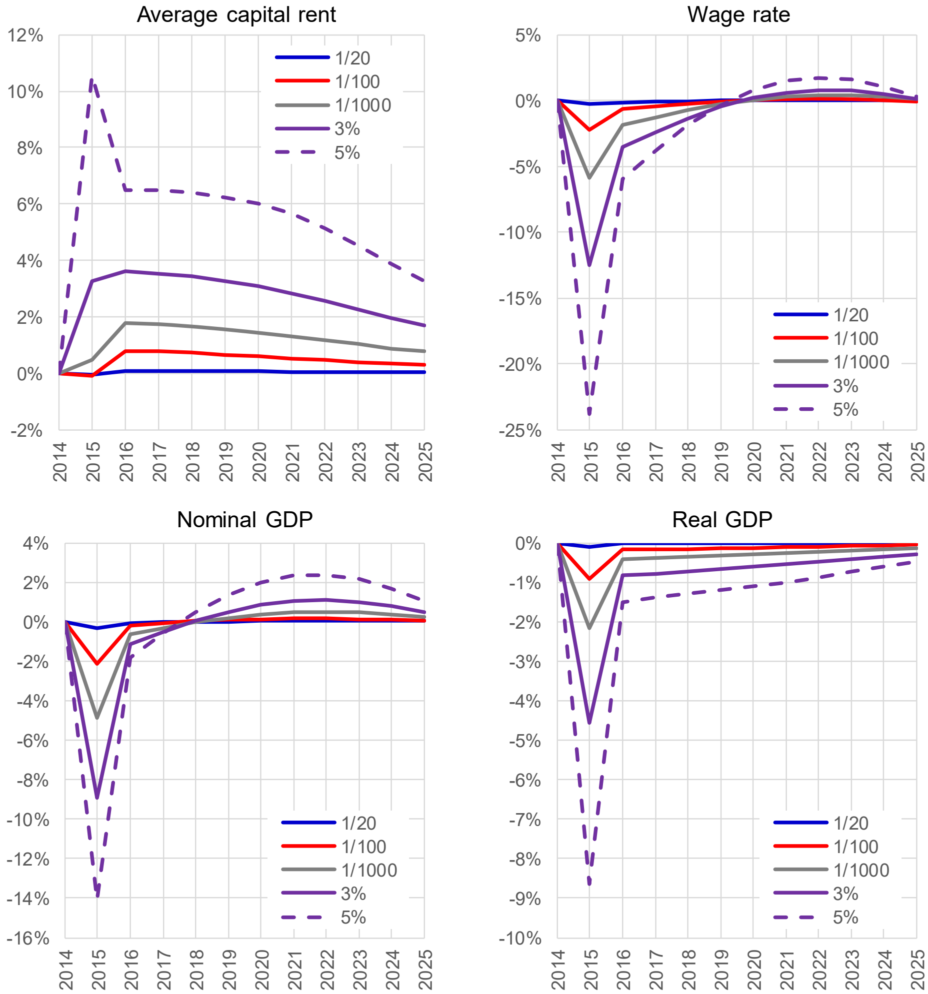

Figure 4: Effects on average capital rents (weighted average over all sector specific capital rents), wage rates, nominal GDP (including relative price effects) and real GDP (at constant prices).

Turning to the second production factor, labor and the associated wage rate, we note that in contrast to capital, labor is not sector specific and is thus perfectly mobile across sectors. After the destruction of capital, labor is relatively more abundant and cannot be used as productively as in the baseline anymore (excess supply). Put differently, due to lower availability of capital, production is also lower which results in reduced labor demand. This, in turn, ultimately translates into lower wages as labor supply is given. Hence, the damage channels put a downward pressure on wages. The reconstruction channel affects wages via the shift from relatively labor intensive consumption to more investment, which also leads to a downward pressure on wages (see Figure 4, upper right panel).

Irrespective of the scenario, we observe a lower wage rate as in the baseline in the year of the flood event (2015), followed by a recovery in the subsequent years. When comparing the effects between capital rents and wage rate, we observe that the labor market reacts stronger than the capital market in terms of prices. Note again that the reconstruction channel is only effective in the year of the flood. Hence, as from 2016 onwards, the effect of lower wages is driven by the relative scarcity effect of capital. As the capital scarcity effect weakens over time, so does the effect on the wage rate. Interestingly, around 2020 wages start to be above baseline levels. This can be explained by two effects: First, the capital scarcity effects weakens over time, making labor more productive. Second, due to capital scarcity and higher capital rents there is a redistribution of income to higher income households (who own more of the capital stock than low income households). Since higher income households have higher expenditure shares for labor intensive consumption than low income households, demand for labor increases and so does the wage rate. The economy-wide effects are displayed by the effects on GDP. Nominal GDP changes closely follow the effects on the wage rate, as labor income is by far the largest source of income in the economy and wages react much stronger than capital rents (**Error! Reference source not found.** 4, bottom left). Changes in real GDP (at constant prices), in contrast, are below baseline levels throughout the whole time horizon as the positive nominal effects from higher prices disappear (Figure 4, bottom right).

With the CGE model, we furthermore investigated welfare effects and indirect sectoral risks. We give again a rough summary here and refer to Bachner et al. (2022) for a comprehensive presentation of results. Taking a closer look at welfare implications of different households, defined as consumption possibilities, we find that consumption possibilities fall below the baseline level in the year of the event for all household groups and also for the government. When looking at the periods after the flood event, we also see that consumption possibilities remain below the baseline level. More importantly distributional effects in terms of gains and losses for different income groups were found, which we discuss in more detail in the next section focusing on WP3.

Turning to the indirect sectoral risk, we find that, in general, sectors are affected by the direct damage to its capital stock (direct risk), but also via changed demand patterns and levels. Demand for goods and services changes due to three reasons: First, there is lower economic activity due to the shock, thus lower intermediate demand. Second, there is lower income and thus lower final demand. Third, there is reconstruction, which increases demand for some activities, but also crowds out other activities. In particular, especially for sectors that produce goods and services for final demand as well as goods and services of the public domain, the indirect risk is very high. For some sectors the lost gross value added is 100-1,000 times higher than the direct damage, due to economy-wide feedback effects. Only about a third of the sectors show a low indirect risk and sectors contributing to reconstruction (construction, buildings, manufacturing of cars, civil engineering etc.) might even benefit from a flood event despite being affected directly.

Next, we now discuss some results of to the agent-based model (ABM). Figure 5 shows the indirect economic effects resulting from a 100-year (red line) and a 1000-year (black line) flood event that destroys dwellings and productive capital. The total direct losses (damages) amount to about 0.7% (100-year event) and 1.57% (1000-year event) of Austrian capital stock, respectively. Furthermore the Figure depicts real GDP levels (upper left panel), real GDP growth (upper right panel), government debt-to-GDP ratio (lower left panel), and the unemployment rate (lower right panel) relative to the baseline scenario in percentage points (pp).[1] The qualitative behavior of the 1/100 scenario is as follows: starting from small negative effects immediately during the first quarter after the disaster (not visible in the yearly average), effects on economic growth turn positive in the short to medium term (2015-2016) due to reconstruction activities. In the long term, primarily due to a multiplier accelerator mechanism (Samuelson, 1939), the economy seems to remain on a higher GDP level than before, while the GDP growth rate returns to its previous value. These effects are most pronounced with an almost 2pp GDP growth rate increase (1000-year event) relative to the baseline scenario in the first year after the flood (2015). In the medium term, the effects decline to a slightly negative impact, while the growth effects in the long term seem to be largely neutral. This behavior i.e., positive short- to medium-term and almost neutral long-term growth effects, especially of moderate flooding disasters inducing long-term positive level effects, is in line with the literature (Botzen et al. 2020). (lower right panel) also demonstrates that—as to be expected according to Okun's law—the change in the unemployment rate is inversely correlated to economic growth: for the 1000-year event, a decline of slightly more than 1pp within two years after the flood consolidates in a 1pp decrease of the unemployment rate in the long term, in line with the effect on the GDP level. Figure 5 (lower left panel) depicts the government debt-to-GDP ratio and shows that the dynamics of the growth and unemployment rates, as well as the transfer we assume to be provided by the government to fully compensate households for their losses of dwellings as catastrophe relief, all lead to an initial fall in this ratio of about 2pp for the 1/100 and 1/1000-year events. In the long term after the flood (2016-2019), the government debt-to-GDP ratio steadily declines to an overall decrease of more than 3pp (1000-year event) due to the long-term increases of GDP levels and the corresponding decrease of the unemployment rate.

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[1] A percentage point (pp) is the unit for the arithmetic difference of two percentages. For example, moving up from 10% to 12% is a 2pp increase, but it is a 20% increase in what is being measured.

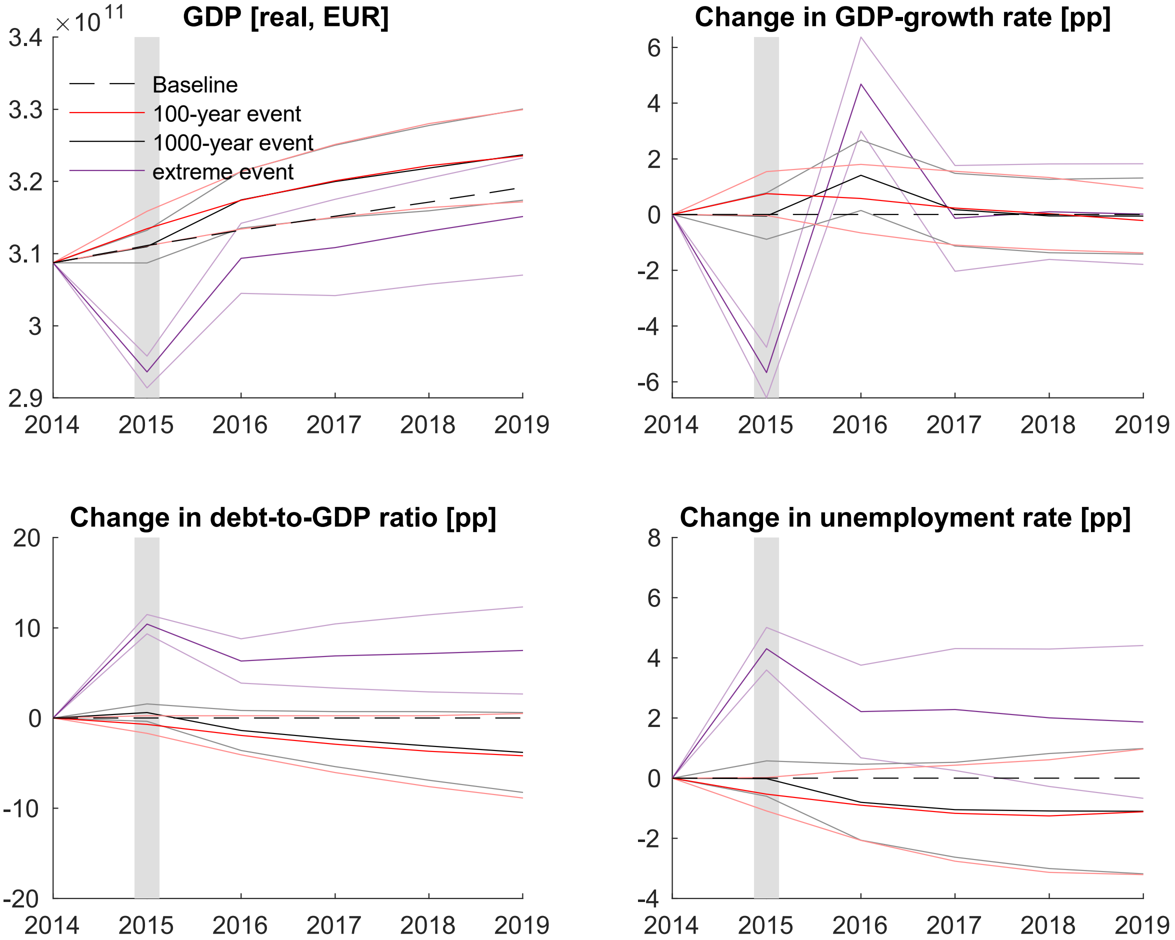


Figure 5: Indirect economic gains and losses of a 100-year (red), 1000-year (black), and extreme (purple) flood event. Time labels on the x-axis indicate the end of each year, and the grey vertical bar marks the first year after the flood. The panels show the effects as changes relative to the baseline scenario in which no disaster happens: real GDP levels (upper left panel), real GDP growth (upper right panel), government debt-to-GDP ratio (lower left panel) and the unemployment rate (lower right panel). Shaded areas cover one standard deviation above and below the mean values, as obtained from 100 independent Monte-Carlo simulations.

An extreme-disaster scenario is also shown in Figure 5 (purple lines). The total direct losses correspond to approximately 5% of the capital stock in Austria. The indirect economic effects after this shock are qualitatively different from the moderate-disaster scenarios. The initial overall effect on GDP growth is pronouncedly negative, with a reduction of GDP growth by about 6pp, see Figure (upper right panel). Due to reconstruction, growth picks up fast in the year after the disaster and surpasses GDP growth of the baseline scenario by the second year after the flood, culminating in a temporary economic boost of about 4pp of additional GDP growth in 2016. However, the multiplier-accelerator mechanism (Samuelson, 1939), as well as production, capacity, and credit constraints drag growth downwards after this point with almost neutral growth effects in the long run. The change in the GDP level (upper left panel) remains also negative in the long term, due to the large initial damages and the cyclical dynamics induced by the disaster. The unemployment rate reacts strongly to the extreme disaster, with an initial increase of more than 4pp right after the disaster and is followed by an increase of about 2pp in the long run. The long-run behavior of the unemployment rate again corresponds to the changes in the level of GDP. Immediately after the disaster, a large initial government transfer to households to compensate for their losses of housing stock as well as substantial decreases in government revenues and GDP lead to a more than 10pp rise of the government debt-to-GDP ratio (see Figure 5 lower left panel). This ratio does not return to its initial level despite the positive economic effects of reconstruction, leaving government finances deteriorated in the long term. A summary of results of the indirect effects is given below.

Milestones:

- Development and calibration of highly detailed macroeconomic models representing the Austrian economy and linking them with flood losses (using data from the damage scenario generator from WP1)
- Estimating indirect risks in terms of selected macro-economic indicators including distributional effects across income groups and sectors (e.g. losers and winners due to a flood event).
- Comparison of a multi-model approach and determining advantages as well as disadvantages of each model (including its limitations) for estimating indirect risk and propagation channels due to flood losses.

WP3: Management of Indirect Risk under a Risk-layering Lens

The first objective and task (Task 3.1.) in WP3 was to test different risk management strategies for indirect risk using the macro-economic modelling approaches. This was based on the results of WP 2 and the input from the stakeholders. The consequences for indirect risk after applying different risk instruments were presented and discussed within a full-day workshop with key stakeholders (Task 3.2) and further revised for a possible policy package relevant for Austria including a new governance approach in regard to indirect risk management against disasters (Task 3.3).

In regards to Task 3.1, we provide a snapshot of the most important results that were used for the stakeholder interactions and the workshop within Tasks 3.2 and 3.3. and focus here on how we quantified the effect of potential management strategies to address negative GDP and welfare as well as distributional effects with the CGE model and strategies related to the financing of the reconstruction effort after natural disasters with the ABM.

Starting with the CGE model, a management strategy designed to counteract the indirect effects of flood damages on GDP and welfare aims to reduce the negative impacts on the society as a whole. One intervention option is to address the influence caused by scarce resources. This means, that spare capacities or flexibility have to be created to meet the demand for labor when needed. The current situation on the Austrian labor market reveals that skill shortage is indeed a prominent problem (Dornmayr and Riepl, 2021). Moreover, the expectation regarding the future development of this situation is worsening within the next three years. A survey undertaken by the economic chamber in Austria in 2021 for example asked 4.272 Austrian companies "How severely is your company currently affected by a shortage of skilled workers?" (Dornmayr and Riepl, 2021). While the majority of sectors face very severe or rather severe shortages, especially sectors relevant for post-disaster activities, such as construction and the production of machinery, are severely affected with more than 80% of companies facing skill shortages. To represent a policy intervention that addresses the issue of scarce resources in the aftermath of a flood event, we assume that Austria can recruit labor from abroad, which creates additional value added and income domestically. For illustration purposes, in Figure 6 we display the GDP losses related to a very severe flood event (1/1000 years) in Figure 6 as well as the effects with three different assumptions regarding the skill shortage-induced capacity constraint on the labor market: (i) a 30% reduction of the capacity constraint, (ii) a 50% reduction of the capacity constraint and (iii) no capacity constraint at all.

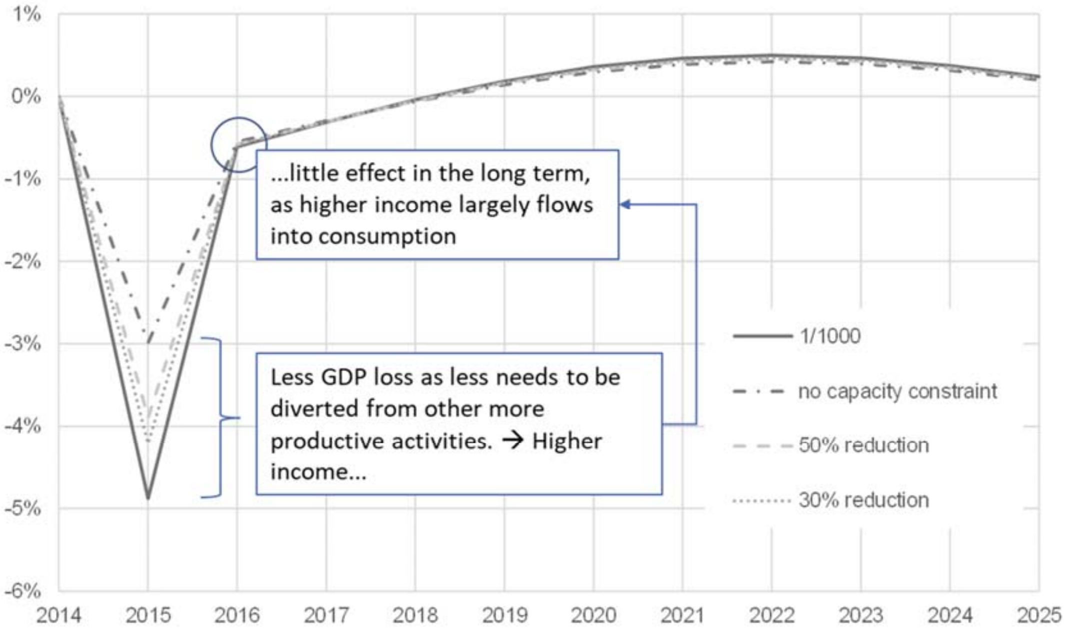


Figure 6: GDP losses with a 1/1000-year flood event (solid line) and under different management strategies addressing skill shortage with a 30% (dotted line), 50% (dashed line) and complete (dashed-dotted line) reduction of skill shortage.

We see that there are positive effects by reducing skill shortage in the year of the event. The lower diversion of production factors from other (otherwise more productive) economic activities reduces the negative effects on GDP as distortions are being reduced and higher income remains with respect to the scenario with a flood event and no indirect risk management strategy. However, adding to economy-wide income can only partly compensate the short-term damage induced by the flood event. Moreover, long-term effects can hardly be addressed. This is the case as only a smaller share of the income contributes to investments, while the majority flows into consumption. The effect is thus mainly visible in the first year, because the respective policy measure does not strongly interfere with capital accumulation. Thus, the damage to the capital stock is difficult to offset by additional income flows.

To address socially unequal distribution effects, we analyzed the effects of a well-known policy measure to support low-income households, which consists of transfers from the public sector to private households, with the CGE model. As a starting point, we consider the disaster fund, a management tool that is already in place in Austria, and adopted the following assumptions: (i) a compensation of damages regardless of income level, (ii) on average, 30 - 50% of the damages are compensated, and (iii) fast payments in the year of the event.

The compensation of flood losses is indeed particularly visible in the first year but also compensates for welfare losses in the longer term. While this represents an important compensation for the lowest income households we also find that socially unequal distribution effects persist in the longer term. Thus, the lowest income household group is the most affected in the long term. Furthermore, high public transfers imply strong negative impacts on public consumption opportunities. As a consequence, the provision of public goods also decreases. As an alternative to the existing mechanisms of the disaster fund, we simulated a compensation scheme that accounts for income levels when compensating capital losses. We assume that only incomes below the median income receive transfers. For the rate of compensation we stick to the upper limit of the average compensation of the disaster fund, which makes up for a compensation of 50% of the damage incurred in the year of the event. While the compensation only implies little improvement for the lower-income households as the damage to them in the first year is relatively smaller, the consequences for the public household are much less severe. Clearly, the compensation of a smaller share of damages does not burden the public budget so much. However, this also implies that public consumption is cut less and therefore the provision of public goods and services is not reduced so much. As discussed earlier, lower-income households tend to be more reliant on public means, whereby the adaptation of the indirect management strategies towards income-dependent compensation schemes, provides additional benefits for lower-income households.

ABMs allow the inclusion of non-linear dynamics of the financial system of an economy. We, therefore, focus in this section on the indirect risks and potential management strategies related to the financing of the reconstruction effort after the simulated natural disasters. To gain further insights, the effects of the availability of debt financing and government funding for the reconstruction are decomposed in Figure 7 for the extreme disaster event. The top-left panel shows the marginal impact of equity, debt, and government financing of the reconstruction on GDP growth. As can be seen in the top-left panel, the availability of debt financing and government funding contributed about one-third of GDP growth in 2016 (one year after the disaster). Even more pronounced are the effects on the unemployment rate (lower-left panel): with the availability of debt financing, the unemployment rate is every year about half a pp lower. Additionally, in 2015 (when the simulated natural disaster occurs) and in 2016, the unemployment rate was half a pp (2015) and one pp (2016), respectively, lower. The marginal impact of government financing on the debt-to-GDP ratio is negative and causes an about 1.5 pp higher debt-to-GDP ratio. On the other hand, the effect of debt financing, in general, is positive and causes an about 1.5 pp lower debt-to-GDP ratio.

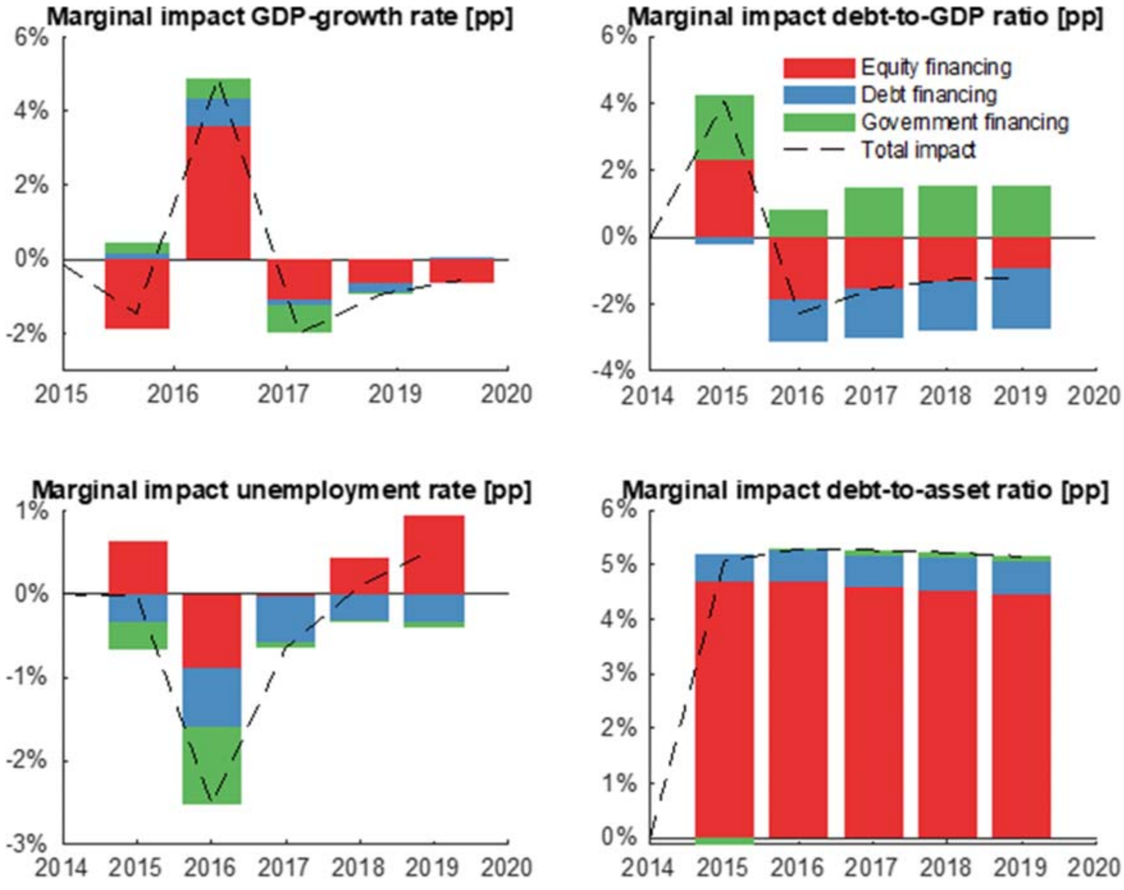


Figure 7: Marginal impact the availability of debt financing and government funding for the reconstruction.

In Task 3.2 we analyzed the question of how indirect risks from natural disasters are and could further be proactively integrated into public flood risk management (FRM) and thus also into climate risk management (CRM). The results presented above were elicited during the stakeholder process accompanying the project and most importantly a full-day stakeholder workshop. The stakeholder workshop was held on February 24th 2022 online from 9 a.m. to 4 p.m. The number of participants varied throughout the meeting with a maximum of 18 participants at one point in time. All in all, participants echoed many of the issues uncovered by our content analysis of the interviews and focus group meetings held throughout 2020 (see section 2). The first problem referred to the lack of a common definition of indirect effects. Achieving a commonly shared definition of what indirect flood effects entail was considered the most pressing issue in order to be able to tackle the issue of managing them. Stakeholders further highlighted the lack of data on indirect effects which would be integral in determining the actual scope of the problem. In this context, stakeholders also lamented the restricted view of costs in connection with management measures, i.e. determining the actual follow-up costs is often neglected and/or lacks transparency. Therefore, data is desperately needed on these costs of structural FRM measures, such as maintenance costs, costs of restoration/renaturation measures or resettlement, etc. in order to give a reliable estimate of the actual costs and benefits of certain management measures.

The second issue addressed was that of iterative risk management, which is of utter importance in order to avoid maladaptation. Especially in connection with repeated shocks, the national budget can be put under severe pressure. In this regard, information as to the expected change in frequency of flood events due to climate change effects would be helpful so as to increase the willingness for political action. Additionally, stakeholders welcome the increased implementation of building back better measures, which could play a role in alleviating some of the financial stress on the national budget. Furthermore, fair cost-sharing of the financial effects following a flood event is of high priority for certain stakeholders. To achieve this, risk awareness needs to be improved and a shift in risk transfer and financing (I.e. from public to private) should be instigated. This way, one could also tackle the problem of moral hazard which can be found especially in connection with the Austrian disaster relief fund. Certain stakeholders highlighted the importance of the relationship between provincial governments and the national park Donauauen. Natural flood protection, as provided by the flood plains in this part of the Danube, is seen to be the most sustainable and suitable flood protection.

The result of the multi-model approach as well as workshop were incorporated within a larger process and policy governance approach (Task 3.3). Indeed, it is important to embed the indirect risk management with already established policy processes, approaches and instruments that were developed for direct risk management. One suggestion taken from the climate risk community is to use a triple-loop learning process going from reacting to reframing and finally transformation. This is also in line with suggestions made towards an increasingly adaptive risk-management framework with a focus on solutions with multiple benefits. We suggest an adapted approach within the context of integrating direct and indirect risk management from a systems perspective. At the core of the integrated direct and indirect risk governance framework lie four steps that are ideally to be embedded in a comprehensive participatory process (Figure 8).

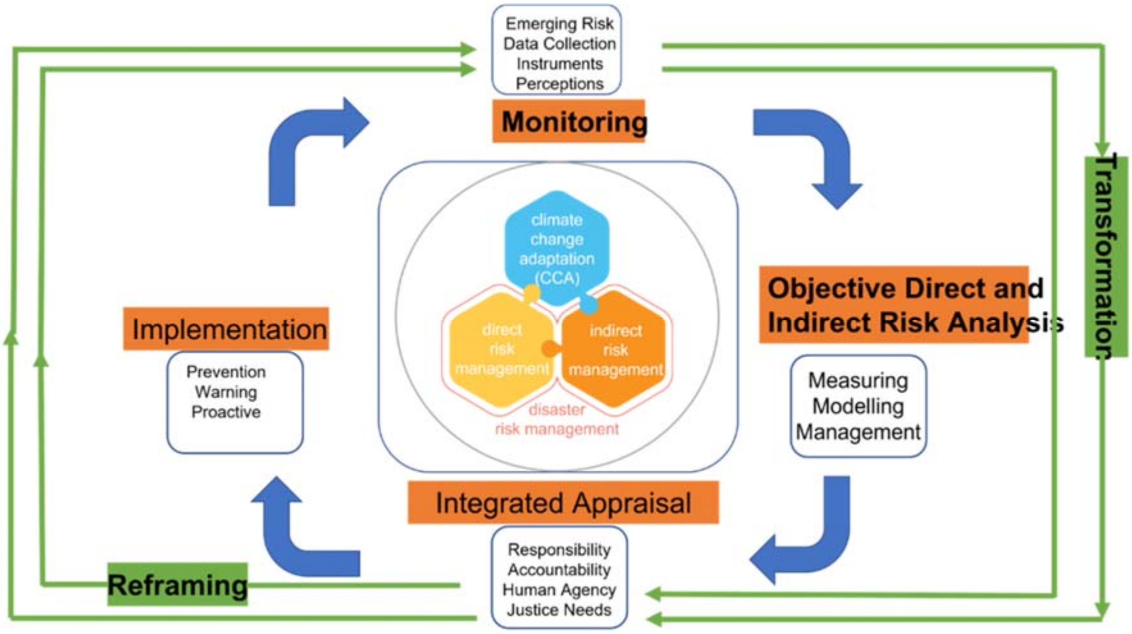


Figure 8: Iterative framework for integrated direct and indirect risk assessment and management embedded in a triple-loop learning process. The illustration at the center shows indirect risk management as its own pillar within disaster risk management (in addition to direct risk management). These two components of disaster risk management in combination with climate change adaptation measures would then form holistic climate risk management aimed at direct and indirect flood risks now and in the future.

Due to space restrictions we cannot go into too much detail and merely focus on the integrated appraisal step. The integrated appraisal step is especially important as it opens up the opportunity to think outside the disaster risk domain and to find overlapping challenges and problems within the non-related disaster systems, such as general economic or social development considerations (as discussed above). Indirect risk management in that regard can be related to current discussions on the triple or multi-dividend approaches. For example, the triple dividend approach (see Surminski and Tanner 2016) suggests a broad case of disaster risk reduction and investments that provide benefits even in the case of absence of disasters. The first dividend relates to avoiding and reducing direct and indirect disaster risk while the second dividend addressed the reduction of background risk for unlocking development. The third dividend focuses on generating development co-benefits that are not dependent on the occurrence of disaster events. The multiple dividend proposition is similar to the triple dividend and basically addresses the two extreme ends of a continuum: One end represents risk management in the disaster domain an approaches it in such a way that co-benefits are created in other policy domains. The other end assumes a sectoral perspective where mainstreaming implies that disaster risk management are integrated into development investments for current and future challenges. Also here, the system perspective, e.g. either looking on the disaster related system or a system which may also be related to disaster risks, is essential and both can be incorporated therefore from a systems perspective.

Climate change impacts can come in through the risk layer approach. As shown in Table 1 losses increase substantially over time and therefore also indirect risk will increase as well (as was also shown in the three modelling approaches). If one assumes that up to the 100 year loss event rather risk reduction and afterwards risk financing should be looked at, we especially see an increase in the tail events (extremes, ie. After the 250 year event) and therefore especially risk financing instruments need to be adapted accordingly to address direct risk. However, in the future and according to our analysis also for the tail events the indirect effects get smore pronounced. Consequently, from an indirect risk-layering a focus on future interdependencies should be taken into account and a possible re-framing of the current risk management strategies have to be looked at, as suggested within our system dependency perspective explained above. A corresponding manuscript is currently produced and envisioned to be submitted to the International Journal of Disaster Risk Reduction.

Milestones:

- Development of risk strategies against indirect risk that are beneficial from different system perspectives.
- Development of a set of policy interventions and processes so that indirect risk management can be embedded within direct risk management strategies.
- General governance framework for indirect risk management developed and applied to Austria in an iterative and step-by-step process.

5 Schlussfolgerungen und Empfehlungen

Currently, only few management instruments are in place to tackle indirect flood risks in Austria, despite the fact that stakeholders recognize indirect flood risks as substantial burdens on both the individual and the national level. Instruments currently in use include privately offered, voluntary insurance products, cost-benefits analysis, as well as critical infrastructure analysis and (inter)national financial aid to assist in quick recovery. One of the main identified reasons why management measures for indirect risks are not yet being implemented is *missing data* on indirect costs of floods – be it in the past nor are there reliable predictions as to how they will develop in the future with the effects of global and climate change. Since such data is not readily available and modelling is tied to intrinsic uncertainties, stakeholders are reluctant to introduce costly measures without being able to ground these decisions on reliable indirect loss data. More fundamentally though, a *clear and collective definition* of what indirect damages are and how to measure them is missing which, too, impedes indirect FRM and which is an issue of great concern among stakeholders.

As indirect damages are difficult to determine, also the allocation of responsibility concerning their management is unclear. In general, responsibilities and competences in the Austrian FRM are departmentalized to a high degree due to the complex nature of the challenge, however, this also leads to *institutional barriers* in the coordination and communication of FRM efforts for indirect risk. With these institutional barriers in place, the development of a systems perspective is hampered, and can lead to one-sided FRM approaches. A broader portfolio of FRM measures which takes into account the spatial and temporal dependencies of floods and their indirect effects on socio-economic dimensions is essential for avoiding false adaptations.

We also found that while a probabilistic approach may be appropriate for direct risk-layering, a focus on connectedness is suggested to be appropriate for indirect risk-layering. Connectedness can be assessed using different measures suggested in the literature, e.g. focusing on the proportion of elements affected or how many elements are too big to fail, or to interconnected to fail etc. The measure used itself ultimately depends on the research question at hand and should be chosen case specific. Furthermore, a system approach is essential for indirect risk management, which requires that the system is appropriately defined -a task which is already quite complex but nevertheless necessary for any kind of such an analysis. To add dimensions and complexity, systems of systems may be constructed, but the basic setup for a risk-layer approach remains, i.e. the clear definition of what is inside the system and what is not. As discussed, ABM and CGE approaches seem especially well suited to explicitly model the indirect effects both from an individual (e.g. elements in the system) as well system level perspective including distributional effects.

When comparing the three model classes at hand, each has strengths and weaknesses and suit different purposes. When doing so, it becomes evident that the different models are suited for analyses of different time horizons. Standard IO models are completely static, i.e. they mimic the very short-term behavior of economies where technological change or changes in production and demand structures are not possible (due to the fixed input coefficients). Hence, IO models can be used to detect bottlenecks or very short-term effects of demand stimulus (assuming that there are none of them). The ABM as used here is best suited to describe short to medium-term effects, i.e. effects over 1-5 years (divided into annual quarters) as it is calibrated to rather short-term behavior and expectations of agents (behavioral heuristics). Finally, the CGE model assumes long-term macroeconomic balances and equilibria and is therefore best used to study the long-term effects of a system intervention. The direct comparison of model results is thus of limited meaningfulness in terms of plain numbers, nevertheless we do so to reveal modelling uncertainty at the science-policy interface, particularly with respect to translational uncertainty, which "results from scientific findings that are incomplete or conflicting, so that they can be invoked to support divergent policy positions" (Sarewitz 2010). We therefore suggest to use a systems approach that enables an integrated analysis from various perspectives, including those not directly related to disaster risk management but focused on development issues more generally. This opens the possibility of a multiple benefits approach to indirect risk management strategies. In addition, changing socioeconomic conditions require adaptive and iterative processes for indirect risk assessment. A toolbox-based approach embedded in such a process is a promising way forward, as it would allow methods, models, and approaches to be linked in a way that highlights the complex nature of such an analysis and thus emphasizes the existence of multiple entry points for indirect risk management

For the two main indirect risks that we identified with the CGE model, negative GDP and welfare effects as well as distributional effects, we performed an analysis of potential management strategies. To overcome adverse societal effects, we aimed to reduce short-term capacity constraints in the CGE model to allow for smooth reconstruction activities. This reflects a reduction of the shortage of skilled workers involved in reconstruction for several sectors. Flood damages imply a lower GDP in the year of the event, with slightly positive nominal effects in the long term driven by price increases. The welfare effects (real effects), however, are stronger than GDP effects and negative over the entire time horizon. The countermeasure via a reduction of shortage of skilled workers has short-term positive effect, but the damage to the capital stock is difficult to compensate via additional income.

Regarding the distributional effects, we found that in the short run, a flood event affects high-income households more than low-income households, as high-income households possess more of the destroyed capital. However, in the long term, low-income households suffer more from increased consumer price levels and changes income than high-income households. To cushion the consequences from flood events, we implemented a countermeasure that mimics the disaster funds in Austria, which provides income-independent compensation right after the event. While this reduces the burden on all households in the year of the event, adverse distributional effects in the long run persist. Thus, managing this indirect risk is possible only to a limited extent with existing measures. Further considerations should include the timeliness of issued compensation payments, taking into account long-term effects, as well as the characteristics of recipients. The ABM model found quite different patterns for different year-event losses. Especially debt financing plays a significant role in regards to indirect effects in the short and long term. Especially the government can be seen as a kind of last resort for needed debt financing in case the economic situation is under heavy stress and borrowing is constrained due to high losses. Various interactions have to be taken here into account, e.g. as was shown, for extreme disaster events the marginal impact of government financing on the debt-to-GDP ratio is negative and causes an about 1.5 pp higher debt-to-GDP ratio. On the other hand, the effect of debt financing, in general, is positive and causes an about 1.5 pp lower debt-to-GDP ratio.

Based on these challenges, we propose establishing a more holistic FRM concept which takes into account the spatial and temporal dependencies of floods and indirect risks, as this has not yet been fully integrated in Austria. Especially policy options where the total i.e. direct as well as indirect damages of floods are factored in and where a more long-term perspective is adopted needs to be developed. As a first step, we recommend introducing indirect FRM as its own pillar within disaster risk management, which can, in combination with climate change adaptation, form effective and holistic climate risk management. As on additional step in putting indirect FRM on track a common definition of indirect effects and how they are measured after events needs to be found. Additionally, the data on documented and/or estimated indirect damage as well as projected climate change effects need to be more widely considered in current and future project planning. High priority should be given to filling the lack thereof and learning processes as well as adaptive measures should be foregrounded which allow for flexible and adjustable decision-making processes. As a consequence, modelling approaches that are able to capture indirect risk should be used not only for the assessment and measurement of it, but expanded to include also risk management options that are targeted at indirect risks.

Restructuring the FRM also requires an increase in inter-agency communication and coordination of management measures to facilitate the flow of information, the streamlining of processes and the implementation of management measures that have a systems perspective at their core. The inclusion of possible indirect risk management options within current direct risk related strategies in Austria is one possible step forward to initiate this process. Thereby, false adaptations can be prevented as best as possible without dismissing neither indirect damage nor climate change effects on the grounds of limited data. A possible risk-layer approach for indirect risk which discriminates between different management options dependent on the interconnectedness of the system at hand (e.g. economic or social) may provide a promising way forward similar to the case of direct risk (Hochrainer-Stigler and Reiter 2021). The Austrian financial management scheme for flood risk provides acute and vital help to those affected by flood damages and great security in planning preventive measures. Nevertheless, a more sustainable risk financing program should be institutionalized which instigates a transfer of risk reduction from the public to private domain. This would not only help tackle the issues of lacking awareness of flood risks but would also help take steps toward a more sustainable financing scheme for the future.

In light of the ever increasing complexity and interconnectedness of economic networks, the interdependencies of climate change risks and the ripple effects expected in human and physical systems in response to climate change impacts (Zscheischler et al. 2018), more holistic and long-term approaches in disaster risk management are needed in the future. Our research should have helped to tackle these challenges and provide future research directions.

C) Projektdetails

6 Methodik

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. 9, 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. 9, 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.

We further analyzed how indirect RM 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 flood risk management (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. As discussed below, we followed a two-step qualitative approach for a formal analysis of these three aspects as depicted in Figure 9. Additionally, we embedded the results found in recent suggestions on direct FRM and CRM strategies for Austria (Schinko et al. 2016; Leitner et al. 2020) and extended these and similar ideas for direct to indirect risks.

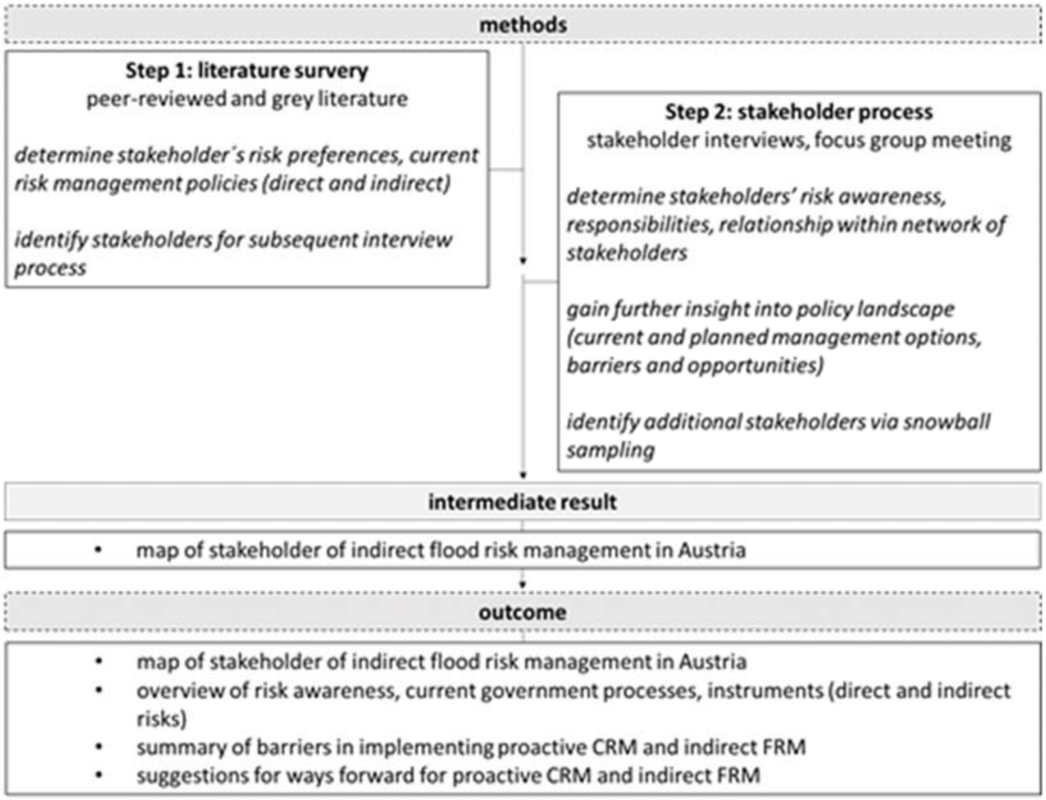


Figure 9. Overview of the main structure of the two-step methodological approach applied (with the main instruments and overall goal given for each step) and its outcome.

For the stakeholder perspective, we prepared a semi-structured interview to address the following research questions: Do stakeholders feel affected by indirect risks? Do stakeholders expect climate change to have an effect on these risks? (risk perception). Which measures are already being taken against indirect risks and what are further policy and practice options? (risk management). Which difficulties and/or obstacles do stakeholders perceive within the Austrian FRM and how can they be tackled? (difficulties and/or obstacles in risk management).

Based on this analysis we further determined based on focus group meetings important key indicators the decision makers would be interested in for the different modelling approaches. We explain some of the most important modeling work for the CGE and ABM next. However, before that we need to address how we avoided the underestimation of flood risk on the country scale as well as the distribution of losses across different agents. This we did through a so-called copula approach. The approach is especially useful in that it enables an analysis of large-scale extreme events on the country level which is an essential prerequisite for a probabilistic macroeconomic analysis. We use information from two previous projects funded within the Austrian Climate Research Programme (ACRP), namely, COIN and Public Adaptation to Climate Change (PACINAS), which provide probabilistic information on the country level regarding losses today and in the future. This includes grid-scale (25x25 km) loss information for the SRES A1B scenario (Nakicenovic and Swart, 2000), which is used as the input to the copula approach in Schinko et al. (2016). This information was used to build up the flood scenario damage generator, which is needed to estimate indirect risks in a probabilistic fashion through our proposed macroeconomic modelling approaches (Table 1). In more detail, in our work the original input for losses on the local level comes from Jongman et al. (2014). Current hazards as well as climate simulations used in this study were obtained from the EU FP6 ENSEMBLES project (http://www.ensembles-eu.org/). These simulations constitute a large high-resolution (ca. 25 km x 25 km) ensemble of climate simulations for Europe. In total, 12 climate simulations derived from a combination of 4 GCMs and 7 RCMs, and covering the period 1961-2100 at a daily time step and forced by the SRES-A1B scenario, were used. Afterwards a 5 km x 5 km grid resolution for LISFLOOD (a hydrological based flood model) with a daily time step for the period 1961-2100 was applied. LISFLOOD simulates water volumes along river channels as primary output. However, the model also provides river water levels (relative to channel bottom) estimated from the simulated water volumes and the cross-sectional (wetted) channel area of the river section. Extreme value analysis was employed to obtain discharge and water levels for every river pixel associated with different return periods (2-5-10-20-50-100-250-500 years). More specially, a Gumbel distribution was fitted to the 30 annual maxima values defined within 4 time windows (1961-1990, 1981-2010, 2011-2040 and 2041-2070), which were interpolated into a continuous series for the period 2000 – 2050. For each of these time windows, the 8 return periods mentioned above were estimated. Hazard will only affect exposed assets which needed to be assessed as well.

It should be noted that there are many different copula types available (Gaussian, Clayton, Gumbel, Frank, Joe -- to mention a few), each describing different types of dependence structures including independence. The flood loss distribution data on the local and basin scale used from Jongman et al. (2014) as described above is used as the input for upscaling distributions to the country level. The different river basin dependencies in Austria are estimated using different copula types C (e.g. Clayton, Frank or Gumbel) and are built on maximum river discharges for the period 1990-2011 for each basin. The loss distributions from each basin are coupled using the given copulas and a minimax ordering approach to finally derive a loss distribution on the country level. To the authors best knowledge, there are only two other models currently available for Austria using a copula approach (Prettenthaler et al. 2015; Schinko et al. 2016). The data used and approach as described above was performed in Schinko et al. (2016) and Mochizuki et al. (2018) specifically for Austria and was performed again in this project and formed the basic input for the agent-based modelling approach via a damage scenario generator. Importantly, we used the so-called SABINA Database which covers all financial statements of all Austrian firms obliged to provide this statement by law (see http://www.bvdinfo.com/en-gb/our-products/company-information/national-products/sabina). Additionally, we can relate the location of firms geographically. Using again an overlay approach we take the exposed elements based on this database with the flood hazard maps from HORA to obtain the number of assets affected for specific flood event types. To the authors best knowledge this is the first time that such high precision data on assets is used within a flood risk mapping approach. In this way we related the over 179 000 firms data with the NACE 2 code as well as the flood zones. Summarizing, not only year-loss events were estimated but also the distribution of losses across different agents in a highly detailed manner available and used as an input to the three models (see Figure 10).

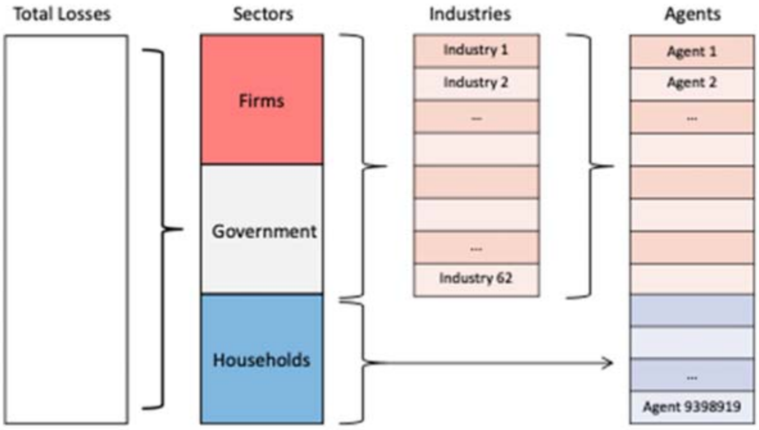


Figure 10. Overview of how total losses are distributed according to sectors and agents

Starting with the CGE model the main idea behind CGE models is, that all markets are cleared simultaneously, meaning that supply equals demand for all goods, services and factors. This "general equilibrium" depicts the economy as a flow equilibrium (usually on an annual basis) which can then be disturbed in a counterfactual experiment by an intervention. After such an intervention the main drivers of system change are relative prices and the associated demand responses. Once an exogenous intervention takes place, relative prices change; e.g. the price of a product might increase due to a new tax that is introduced. In turn, economic agents (producers and consumers) react to this change in relative prices by changing their demand patterns (lower demand for more expensive products and higher demand for the now relative cheaper products), however within their technological and resource/budget constraints. This first round effect of reactions again triggers second round effects etc. Ultimately this adjustment process continues until a new equilibrium is reached in which all markets are cleared again, but now at different prices and quantities than before. By comparing the new equilibrium to the old one, one can isolate the effects of the exogenous intervention. This comparison of two equilibria is referred to as "comparative static" analysis. When connecting annual equilibria via capital accumulation (investment in period t determines the capital stock and the equilibrium in period t+1) we speak of a "recursive dynamic" approach that is able to project the development of the economy into the future. Usually this is done by also including other assumptions of expected socio-economic developments (e.g. population growth or technological change). One can then compare different pathways into the future to each other rather than single years.

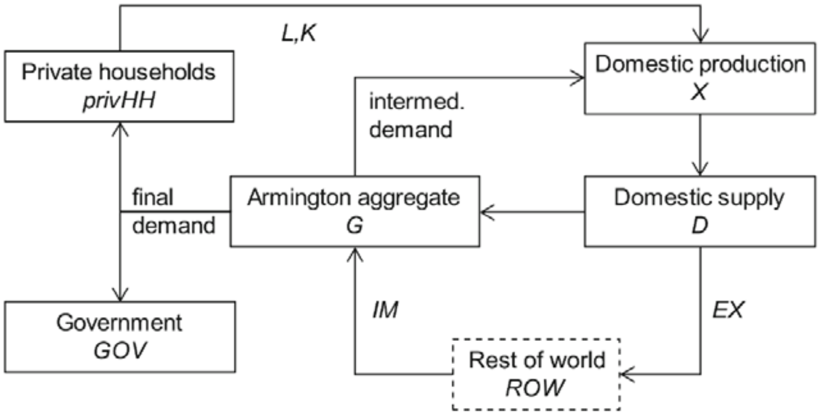


Figure 11: Conceptual overview of a CGE model (source: Bachner et al., 2015, p. 109)

Figure 11 illustrates the conceptual framework of a CGE model. Private households are endowed with the production factors capital (K) and labor (L), which are provided via factor markets to domestic production (X). Together with inputs from other sectors (intermediate demand), domestic sectors generate output, which is either supplied to foreign countries as exports (EX), or remaining in the domestic market. The so called "Armington aggregate", combines imports and domestic products, which are then supplied at the domestic market for either final demand (private and public consumption as well as investments) or intermediate demand. The system is thus closed and driven by factor supply.

The WEGDYN-AT model, which is used in the analysis, is a recursive-dynamic, multi-sector, small-open-economy CGE model calibrated to the Austrian economy. It builds upon the static version of Bachner (2017) but has been enhanced to a recursive-dynamic version as given in Mayer et al. (2021). We calibrate the model (flow equilibrium of the first year) to a social accounting matrix (SAM) of the year 2014, which is based on an input-output table of 72 NACE-classified economic sectors (Statistics Austria, 2014). Elasticities of substitution are taken from econometric estimates provided in literature (Okagawa & Ban, 2008). The model equations represent a mixed complementary problem and are written in the MPSGE language using the programme GAMS. We solve the model using the PATH solver (Ferris & Munson, 2000). We model Austria as a small open economy, meaning that Austria is not able to influence world market prices by its trade behavior. In the model other regions than Austria are not modelled explicitly, but foreign trade is accounted via trade flows to and from Austria. For importing foreign goods and services foreign exchange is necessary, which is obtained by exporting goods and services. Foreign trade is implemented according to the Armington assumption (Armington, 1969), meaning that domestically produced goods and imported goods are imperfect substitutes and as such treated differently subject to sectoral differentiated elasticities of substitution. Foreign trade is closed by assuming a fixed current account balance, which grows with GDP. The current account is balanced via net-capital inflows of opposite sign (i.e. the capital account). As numeraire we choose the foreign exchange price level.

Flood damages are implemented as a reduction of the sector-specific capital stock. This assumption is based on the determination of damage data in the catastrophe model that reports damaged capital per economic sector. Flood damages destroy productive capital, i.e. capital that is used as an input factor in sectoral production in the CGE model, which affects production in the year of the shock.

Regarding the implementation of indirect risk management strategies in the CGE model, we make assumptions to represent the two strategies described above in section 4. The first strategy is designed to counteract the negative impacts on the society as a whole, while the second aims to reduce socially unequal distribution effects. To represent a policy intervention that addresses the issue of scarce resources in the aftermath of a flood event, we assume that additional labor force can be recruited from abroad. In the CGE model, this is represented by additional availability (and thus income) of labor in the year when reconstruction activities take place. To show plausible ranges, we make three different assumptions regarding the skill shortage induced capacity constraint on the labor market: (i) a 30% reduction of the capacity constraint, (ii) a 50% reduction of the capacity constraint and (iii) no capacity constraint at all. To address the socially unequal distribution effects, we implement a policy measure to support low-income households, which consists of transfers from the public sector to private households. Based on the disaster fund, a management tool that is already in place in Austria, we adopt the following assumptions: (i) a compensation of damages regardless of income level, (ii) on average, 30 - 50% of the damages are compensated, and (iii) fast payments in the year of the event. This is represented in the CGE model by additional transfers from public to private households based on the amount of destroyed capital.

Regarding the Agent Based Model we use and adapted the one by Poledna et al. (2018). This ABM includes all institutional sectors (financial firms, non-financial firms, households, and a general government). The firm sector is composed of 64 industry sectors according to national accounting conventions and the structure of input-output tables. The data come from national accounts, sector accounts, input-output tables, government statistics, census data, and business demography data. Model parameters are either taken directly from data or are calculated from national accounting identities. For exogenous processes such as imports and exports, parameters are estimated. The model furthermore incorporates all economic activities classified by the European system of accounts, both for producing and distributive transactions. All economic entities, i.e., all juridical and natural persons, are represented by heterogeneous agents. Markets are fully decentralized and characterized by a continuous search and matching process that allows for trade frictions. Agent forecasting behavior is modeled by parameter-free adaptive learning, in which agents estimate the parameters of their model and make forecasts using their estimates, as would econometricians do. For that, we follow the approach of Hommes & Zhu (2014), in which agents learn the optimal parameters of simple parsimonious AR(1) rules. The ABM is validated based on historical data by demonstrating comparable performance to standard DSGE and VAR models. We apply the ABM to study indirect economic losses from flood events in Austria. The damage-scenario generator simulates a shock to individual agents from the ABM, which subsequently alter their behavior and create higher-order indirect effects over a given period. The ABM and the integration of the damage-scenario generator is done by shocking the individual agents as determined by the scenario generator (see Figure 12).

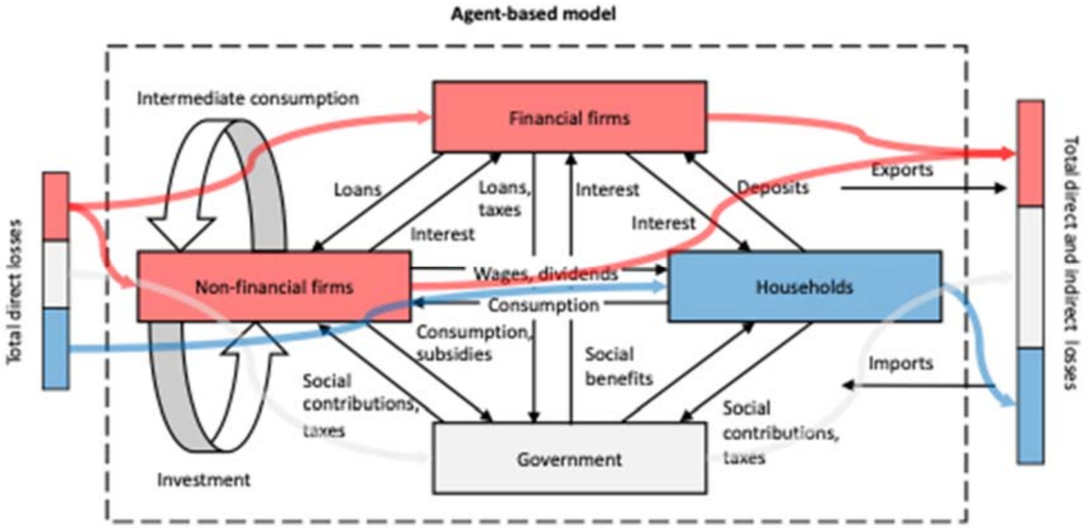


Figure 12: Conceptual framework of the Agent Based model

The insights gained from the stakeholder interviews held in the beginning and throughout the project, the model results as well as the comparison between the different modelling approaches applied and possible instruments and policies found were presented to a group of stakeholders on February 24, 2022 from 9 a.m. to 4 p.m. The overall aim of the workshop was to not only present our findings but also to informally discuss them and receive further input and feedback from the participants. Participation varied throughout the workshop with a maximum of 18 people attended the workshop at a time. Due to the COVID-19 pandemic and for safety reasons, the workshop was moved from an in-person meeting at IIASA to online. Stefan Hochrainer-Stigler facilitated the workshop and discussion rounds following the presentations held by

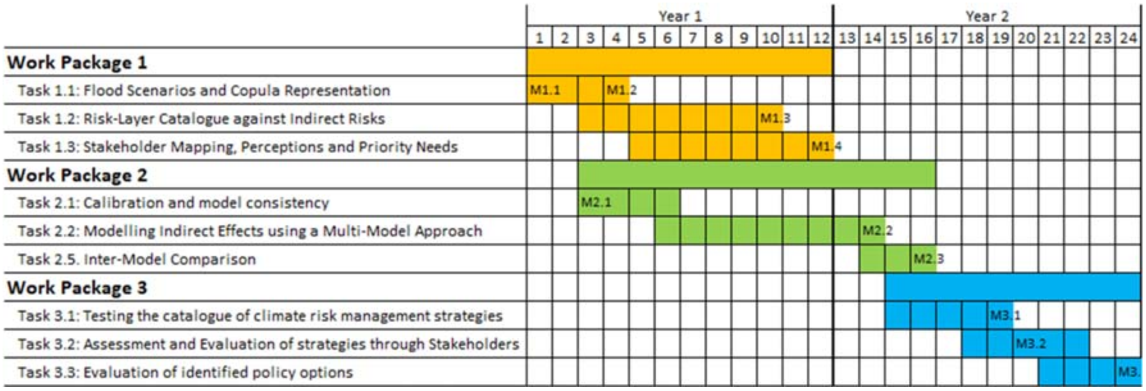
- Stefan Hochrainer-Stigler (on the Damage Scenario Generator)
- Gabriel Bachner and Nina Knittel (on the findings of the CGE modellings)
- Sebastian Poledna (on the results of the ABModellings)
- And Karina Reiter (on the insights from the stakeholder interviews, I.e. stakeholder perspectives, as well as the stakeholder map and stakeholder interactions)

Group discussions, Miro, Mentimeter and the chat function in zoom were used to collect ideas and feedback and gauge stakeholders' risk awareness levels. The insights were integrated in a final modelling round and used to update the inventory of stakeholder perspectives. As discussed above, the integrated qualitative and quantitative research was embedded in an iterative and adaptive direct and indirect risk management approach based on risk governance concepts and suggestions from the climate change research community, including the latest IPCC reports.

7 Arbeits- und Zeitplan

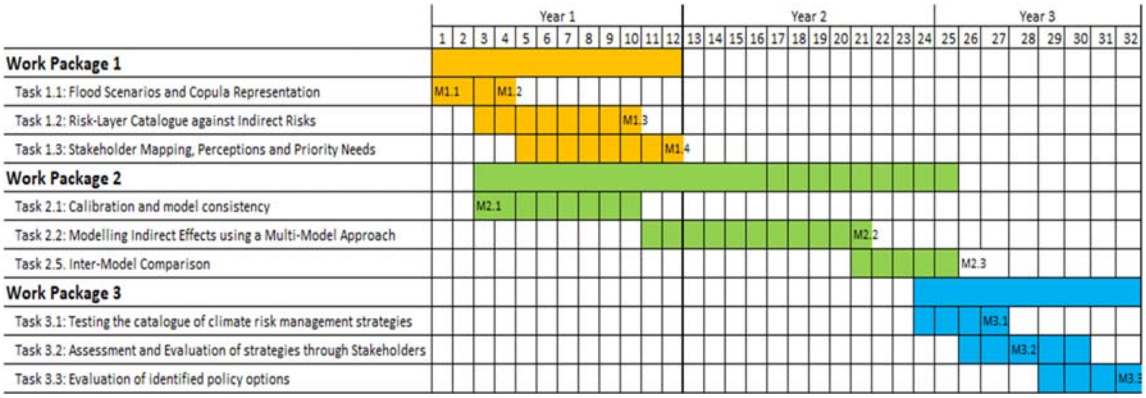
Table 3 and 4 show the original and actual work and time schedule. There are differences in the two schedules. Initially, MacroMode had a project duration of 2 years, starting from 1.11.2019 to 31.10.2021. However, due to the COVID-19 pandemic and the need to restructure the stakeholder process and general difficult situation in that regard the project deadline was extended to 30.06.2022. The project no-cost extension enabled us to finalize the workshop results, particularly the engagement with experts and the completion of the modelling analysis.

Table 3: Original work and time schedule



	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Work Package 1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧												
Task 1.1: Flood Scenarios and Copula Representation	M1.1	🟧	🟧	M1.2																				
Task 1.2: Risk-Layer Catalogue against Indirect Risks			🟧	🟧	🟧	🟧	🟧	🟧	🟧	M1.3														
Task 1.3: Stakeholder Mapping, Perceptions and Priority Needs					🟧	🟧	🟧	🟧	🟧	🟧	🟧	M1.4												
Work Package 2			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
Task 2.1: Calibration and model consistency			M2.1	🟩	🟩	🟩																		
Task 2.2: Modelling Indirect Effects using a Multi-Model Approach						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	M2.2										
Task 2.5. Inter-Model Comparison														🟩	🟩	M2.3								
Work Package 3															🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Task 3.1: Testing the catalogue of climate risk management strategies															🟦	🟦	🟦	🟦	M3.1					
Task 3.2: Assessment and Evaluation of strategies through Stakeholders																		🟦	🟦	M3.2	🟦	🟦		
Task 3.3: Evaluation of identified policy options																					🟦	🟦	🟦	M3.

Table 4: Actual work and time schedule



	Year 1												Year 2												Year 3							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Work Package 1	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧																				
Task 1.1: Flood Scenarios and Copula Representation	M1.1	🟧	🟧	M1.2																												
Task 1.2: Risk-Layer Catalogue against Indirect Risks			🟧	🟧	🟧	🟧	🟧	🟧	🟧	M1.3																						
Task 1.3: Stakeholder Mapping, Perceptions and Priority Needs					🟧	🟧	🟧	🟧	🟧	🟧	🟧	M1.4																				
Work Package 2			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩							
Task 2.1: Calibration and model consistency			M2.1	🟩	🟩	🟩	🟩	🟩	🟩	🟩																						
Task 2.2: Modelling Indirect Effects using a Multi-Model Approach											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	M2.2											
Task 2.5. Inter-Model Comparison																					🟩	🟩	🟩	🟩	🟩	M2.3						
Work Package 3																								🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Task 3.1: Testing the catalogue of climate risk management strategies																								🟦	🟦	🟦	M3.1					
Task 3.2: Assessment and Evaluation of strategies through Stakeholders																										🟦	🟦	M3.2	🟦	🟦		
Task 3.3: Evaluation of identified policy options																													🟦	🟦	🟦	M3.3

8 Publikationen und Disseminierungsaktivitäten

Regarding scientific output based on WP1 work three papers in high-impact journals (within the disaster domain) were published. WP2 was highly computationally intensive including calibration and testing of the models and lead to one near final publication in an international high-impact journal. Two more papers from the work done in WP3 are currently in preparation, one regarding indirect risk governance and one in regard to the modelling of risk management options to reduce indirect risks from a multi-model perspective.

Regarding dissemination activities we already produced two factsheets for a general audience (based on work from WP1 and WP2) and a final one (based on WP3) is in preparation. Furthermore, we presented our results in several workshops and conferences throughout the project period. For more details we refer to the publications below.

Publications in scientific journals

Hochrainer-Stigler, S., Colon, C. , Boza, G. , Poledna, S., Rovenskaya, E. , & Dieckmann, U. (2020). Enhancing Resilience of Systems to Individual and Systemic Risk: Steps toward An Integrative Framework. International Journal of Disaster Risk Reduction 51 e101868. 10.1016/j.ijdrr.2020.101868.

Hochrainer-Stigler, S. & Reiter, K. (2021). Risk-Layering for Indirect Effects. International Journal of Disaster Risk Science 12 770-778. 10.1007/s13753-021-00366-2.

Reiter, K., Knittel, N., Bachner, G., Hochrainer-Stigler, S., (2022) Barriers and ways forward to climate risk management against indirect effects of natural disasters: a case study on flood risk in Austria, Climate Risk Management, https://doi.org/10.1016/j.crm.2022.100431

Bachner G., Knittel, N., Poledna S., Hochrainer-Stigler, S., Reiter, K., Revealing Indirect Risks in Complex Systems: A Highly Detailed Multi-Model Analysis of Flood Events in Austria, submitted to *Risk Analysis* 03/2022 (under revision).

Hochrainer-Stigler, S., Reiter, K., Knittel, N., Bachner, G. And Poledna Sebastian (2022). Management of Indirect Risk due to Extreme Flood Events in Austria: Challenges and Ways Forward, submitted to the Economic Policy Papers (in revision).

Hochrainer-Stigler, S., Reiter, K., Knittel, N., Bachner, G. And Poledna Sebastian (2022). Governance of Indirect Risk: A case study in Austria. (in preparation)

Working papers

Bachner, G., Knittel, N., Poledna, S., Hochrainer-Stigler, S., Reiter, K., Pflug, G. (2022), Revealing the indirect risks of flood events: A multi-model assessment for Austria, Wegener Center Scientific Report 95-2022, Wegener Center Verlag, University of Graz, Austria, March 2022. ISBN 978-3-9504700-4-8

Conference Presentations

Hochrainer-Stigler, S. (2021) (invited). A Systems Dependency Perspective for Individual, Compound and Systemic Risks. IDRiM Conference, 22-24 September, Kyoto, Japan (virtual).

Hochrainer-Stigler, S. (2021). Systemic Risk and Network Dynamics. IDRiM Conference, 22-24 September, Kyoto, Japan (virtual).

Hochrainer-Stigler, S. and Handmer, J. (2021) (invited). A Systems Dependency Perspective for Individual, Compound and Systemic Risks. Compound Weather and Climate Events. 12-15 January, Bern, Switzerland.

Hochrainer-Stigler (2020). Systemic risk, compound events and cascading effects. IDRiM Virtual Workshop for Interactive Discussions between Senior and Early-Career Scientists, 23-24 September 2020, Kyoto, Japan

Hochrainer-Stigler, S. et al. (2020). Macroeconomic Modelling of Indirect Risks for Climate Risk Management. Climate Day 2020, 12-13 April, Climate Change Center Austria.

Fact sheets and policy briefs

Reiter, K., Hochrainer-Stigler, S., Bachner, G., Knittel, N. & Poledna, S. (2022). Indirect flood risk management in Austria: Challenges and ways forward. International Institute for Applied Systems Analysis (IIASA) and Wegener Center for Climate and Global Change, University of Graz

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Bachner G. and Knittel, N. (2022), Wer trägt die Kosten der Klimakrise in Österreich?, blog post series „der ökonomische Blick" in the Austrian newspaper Die Presse, 02/05/2022, https://www.diepresse.com/6132670/wer-traegt-die-kosten-der-klimakrise-in-oesterreich?

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Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte sowie die barrierefreie Gestaltung der Projektbeschreibung, übernimmt der Klima- und Energiefonds keine Haftung.

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