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Towards a comprehensive Assessment of Climate Change Adaptation Measures in Switzerland

ESS 511 Master's Thesis

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Abstract

This thesis presents a comprehensive database of climate change adaptation measures for Switzerland. It is the first of its kind, stock-taking adaptation measures for eleven risks, different actors, target audiences, and categories. In its current form, the database lists 236 measures. The primary focus areas include heat-related risks, droughts, flood damage, and the spread of harmful organisms. The "Cantonal level" was identified as the main actor to implement the adaptation measures, with 99 measures assigned to it. The feasibility and effectiveness of these measures were assessed, revealing that while most are highly feasible, their effectiveness varies, with only 33 measures demonstrating high effectiveness. The measure category "Technical implementation" is among the most effective categories. Measures such as "Climate-adapted buildings" and "Ensuring hydropower production" are highly feasible and effective, making them top priorities for implementation. The total estimated investment for the 45 most quantifiable measures amounts to CHF 9.3 billion, with annual costs of CHF 137 million, primarily borne by the cantonal level. The findings emphasize the importance of prioritising measures with high feasibility and high effectiveness, such as "Ensure water supply", while supporting essential but less feasible measures like "Artificial snowmaking". The database should be viewed as foundational starting point for further analyses and the inclusion of additional measures, risks, or categories that are currently absent. The database, though foundational, is crucial for mitigating the economic, societal, and ecological impacts of climate change in Switzerland and serves as a basis for ongoing and future efforts to enhance climate resilience.

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Acronyms and Abbreviations

AI	artificial intelligence 13
FFA	Federal Finance Administration 24
FOCP	Federal Office for Civil Protection 7, 73
FOEN	Federal Office for the Environment 13, 14
FOPH	Federal Office of Public Health 13
FSO	Federal Statistical Office 23, 24
GDP	Gross Domestic Product 6, 24
GEAK	Building energy certificate of the cantons 23
GST	Global Surface Temperature 1
HWS	Heat warning system 6, 63, 64, 74
IPCC	Intergovernmental Panel on Climate Change 1, 2, 6, 8, 37, 58, 59, 63
LID	Low Impact Development 66
NCCS	National Centre for Climate Services 3, 6, 7, 14, 16, 57
RCP	Representative Concentration Pathway 2, 7, 8, 22, 67, 71, 75, 76
SD	standard deviation 22, 37–39, 43, 46
VLYL	Value of a lost year of life 75
VoSL	Value of a Statistical Life 5, 63, 75

1. Introduction

The world of today faces many challenges. The ongoing climate change is one of them and will have large impacts on life on Earth (IPCC 2023; Peñuelas et al. 2013). In the scientific community, climate change has been widely acknowledged for over 30 years now (IPCC 1990). Furthermore, global institutions such as the United Nations and policy makers around the world see the need for action regarding climate change. The United Nations defined 17 Sustainable Development Goals (SDG) with 169 targets to achieve by 2030 (United Nations 2023). Many of them are directly or indirectly linked to climate change. Current weather and climate undergo significant changes which result in a higher frequency and a stronger intensity of weather extremes such as droughts, floods, and heat waves (Fischer & Knutti 2015; IPCC 2022). Not only extreme events will become more fierce, but climate change will also lead to warmer temperatures, and enhance and change precipitation patterns (Fischer & Knutti 2014; IPCC 2023; Tradowsky et al. 2023). In the second decade of the 21st century (2011-2020), the observed Global Surface Temperature (GST) was 1.09°C above the reference period 1850-1900 (IPCC 2023). The increase of the GST is stronger over land (1.59°C). Central Europe has experienced a stronger trend in the warming compared to the rest of the world (Fischer & Knutti 2014). The likelihood for an extreme rainfall event has increased by a significant margin, accompanied by an increase of the 1-day maximum rainfall event (Tradowsky et al. 2023). Consequently, every economic and ecologic sector is affected by the impacts of climate change (IPCC 2022; Jan Trenczek et al. 2022). Hence, the rapid increase of extreme weather events calls for actions such as mitigation and adaptation. It becomes clear that adaptation to climate change is a growing development priority and already is an urgent necessity in some cases (Webber 2016). Through the Intergovernmental Panel on Climate Change (IPCC) reports, the Kyoto Protocol and the Paris Agreement, the global climate found its way into the global and national politics to find ways to prepare and respond to climate change (Livingston, Lövbrand, & Alkan Olsson 2018). The goal of the IPCC reports is to help and inform policymakers with adapting to climate change based on scientific evidence. Practitioners also contribute to the IPCC report and represent 15% of the AR6 WG2 chapters (Howarth & Viner 2022). However, it is sometimes difficult for the messages to trickle down to the practitioners as end-users such that the usability of the IPCC report is reduced in terms of implementation. In the case of Switzerland, this thesis narrows the gap between the end-users and the scientific community by listing and analysing various adaptation measures and analysing their feasibility and effectiveness. Furthermore, for some of the adaptation solutions, a cost analysis will be performed.

1.1 Motivation and Context

Switzerland, as a country in Central Europe with temperate climate in the northern part, a Mediterranean climate in the south, and the Alps will be strongly affected by the climate change (Scherrer & Schwierz 2018). Since the beginning of the instrumental measurements for temperature in 1864, the long-term annual temperature trend was by +1.4°C/100 years which translates to a total warming of +2.2°C from 1864 to 2020 (MeteoSchweiz 2021). An acceleration in warming has been evident since 1980s, with nine of the ten hottest years occurring in the current century (FOEN 2021). By mid-century (around 2060), the average summer temperature might raise by +4.5°C under the Representative Concentration Pathway (RCP) 8.5 scenario (CH2018 2018). More and stronger heat waves and dry periods are most likely a key change for future summers. An increase in the daily mean temperatures increases the heat-related mortality (Baccini et al. 2011; Lee, Röösli, & Ragettli 2021). Due to a high correlation of the mean temperature (T_{mean}) with the maximum temperature (T_{max}), an increase in the T_{mean} also results in higher maximum temperatures (Ragettli et al. 2023). This is visible in the hottest 1-, 3-, and 7-day periods of the year in which the average temperatures have increased by 1.9 to 2.3°C from 1901 to 2015 (Scherrer et al. 2016). As a result of rising mean and extreme temperatures, heat-related mortality is projected to increase by 30% under RCP4.5 by 2050. Additionally, heat exposure currently results in labor productivity losses amounting to CHF 665 million. These losses are expected to increase by 8% under RCP2.6 or by 65% under RCP8.5 by 2050 (Stalhandske et al. 2022).

From 1960 to 2010, precipitation extremes significantly increased by around 10% (Fischer & Knutti 2014). In Europe, an increase of the mean precipitation for northern Europe is expected while it decreases in southern Europe (CH2018 2018).

In Switzerland, however, the picture is less distinct. Here, annual and seasonal precipitation levels have not shown significant changes since the beginning of measurements (FOEN 2021). However, an exception is the observed winter precipitation on the north side of the Alps, which has increased by 20% over the past 100 years. However, in the Northern Alps, changes were detected for precipitation extremes such as the highest 1-day precipitation totals with an average increase of 10.4% per century. Furthermore, the number of days with extreme precipitation exceeding the 99th percentile grew as well, by +26.55% over a century (Scherrer et al. 2016). Future precipitation patterns shows a regime shift with an increase of winter precipitation while the summer precipitation decreases (CH2018 2018). Combined with increased summer temperatures, water scarcity might develop. Water scarcity potentially leads to problems for the national supply due to low water levels in the rivers, and crop shortfalls (Swiss Confederation 2020).

In Switzerland, the National Centre for Climate Services (NCCS) coordinates projects in climate change mitigation and adaptation. With the action plan 2020-2025 on adaptation to climate change in Switzerland, the NCCS-Impacts program launched seven different projects with the aim 'to develop user-oriented climate services as decision support for planning in the field of climate change mitigation and adaptation' (NCCS 2023). This thesis contributes to project 5 'Costs of climate change impacts in Switzerland' aiming to create a comprehensive database on adaptation measures to climate change, including an assessment of the feasibility and effectiveness.

1.2 Objectives and Research Questions

As part of my Master thesis, I will focus on a selection of climate risks. The basis for this selection was the Report on Climate Risk in Switzerland by the Swiss Federal Office for the Environment ("Klimabedingte Chancen und Risiken") (Köllner et al. 2017). Within the project team, a qualitative assessment based on different criteria (e.g. quantifiability of damage) was performed. The risks are rising heat stress levels, increasing drought, ascending snowfall line, increasing flood risk, and spreading of harmful organisms, diseases, and invasive species. This thesis tracks two main objectives. The first one is to create a comprehensive database of adaptation measures to climate change in regards to the selected climate risks. The second objective is to assess the political, social, environmental, and technological feasibility of adaptation measures with proxies created for the database. Additionally, for discrete adaptation measures, an assessment of the costs of implementation will be done. These objectives lead to the following research questions:

- Which adaptation measures are available or could become available in Switzerland?
- What is the effectiveness and feasibility of these adaptation measures regarding the political, social, environmental, and technological aspects?
- At which administrational level (Federal Government, canton, municipality, or private sector) is need for action?
- What are the costs of selected adaptation measures for the different risks of climate change in Switzerland?

2. Scientific Background

2.1 Risks and Impacts of Climate Change

Climate change poses significant risks and impacts on a global scale. The rise in global temperatures, and increasing frequency of extreme weather events are visible signs of the consequences (Fischer & Knutti 2015; IPCC 2023). These changes have profound effects on natural ecosystems, human health, agriculture, and economies worldwide. The increase in global temperatures is one of the most critical risks of climate change. Studies have shown that the global average temperature has risen by more than 1.2°C since pre-industrial times (IPCC 2023; Matthews & Wynes 2022). In the 2015 Paris Agreement, the United Nations Framework Convention on Climate Change (UNFCCC) agreed to *'hold the increase in the global average temperature to well below 2° C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5° C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change'* (UNFCCC 2015). However, the warming trend is expected to continue, leading to more frequent and severe heatwaves, and might surpass the 1.5°C level before 2029, possibly even around 2026 (Henley & King 2017; IPCC 2023; Matthews & Wynes 2022). More frequent and intense periods of extreme heat pose a significant health risks, including heatstroke, cardiovascular problems, and exacerbates pre-existing health conditions (Meade et al. 2020). In order to reduce such risks, mitigation and adaptation to climate change are necessary. An example from Spain shows the impact of adaptation regarding heat-related mortality. Without adaptation, the annual heat-related mortality in 2021-2050 will be 1414 deaths/year, rising to 12'219 deaths/year for 2051-2100. With adaptation however, the values reduce to 647 and 997 death/year, respectively. The annual costs of the attributable mortality for the period 2051-2100 are €53'217 million without, and €4'108 million with adaptation with a Value of a Statistical Life (VoSL) of €4.27 million (Díaz et al. 2019). Adaptation measures such as air conditioning showed to significantly reduce the vulnerability to heat

(Åström et al. 2017; Lee, Röösli, & Ragettli 2021). Increasing global temperature does not only affect human health, but also influences the Gross Domestic Product (GDP). An increase of the global temperature by 1°C reduces the worlds GDP by 12% (Bilal & Känzig 2024). Adaptation to climate change can significantly reduce the expected annual damages as a study of Haer et al. (2020) shows. Not only the frequency and intensity of heat extremes increase, but also for heavy precipitation and floods (Fischer & Knutti 2015). The intensity of maximum 1-day rainfall events has already increased by 3-19% in the summer season, and the possibility of such an event increased by a factor of 1.2-9 compared to a 1.2°C colder climate (Tradowsky et al. 2023). Enhancing the drainage capacity with integrated flood management schemes reduces flood volume by 5.6 to 14.9% (Sun et al. 2021). Adapting buildings to increasing floods can prevent damage in the order of 1 billion euro or larger (Botzen, Aerts, & van den Bergh 2009).

To combat the impacts of climate change, the IPCC AR5 lists approximately 121 adaptation options (Singh et al. 2020). In the IPCC AR6 chapter 13 "Europe" about 540 actions against climate change were taken by different European cities (Bednar-Friedl et al. 2022). "Informational adaption actions" is the largest group with 171 actions, followed by 52 educational measures. As heat-related challenges are expected to increase, the IPCC AR6 analysed 27 adaptation measures. Especially, Heat warning systems (HWSs) have received a lot of attention to verify their effectiveness and cost-efficiency (Ebi et al. 2004; Toloo et al. 2013; S. Williams et al. 2022).

2.1.1 The National Centre for Climate Services (NCCS)

With the strategy for adaptation to climate change in Switzerland ("Strategie Anpassung an den Klimawandel in der Schweiz") in 2012, the Swiss Federal Council provided guidelines for a coordinated approach to adapt to the impacts of climate change (FOEN 2012). In 2014, the Federal Office of Meteorology and Climatology MeteoSwiss was ordered a mandate to provide regular updates of climate change scenarios (Swiss Confederation 2014). In 2015, the NCCS was founded by different partners to develop and provision climate services and coordinate projects around climate change and its mitigation. The CH2018 scenarios are the result of the Federal Government's first action plan on climate adaptation which also lay the foundation for the second action plan (CH2018 2018). In Switzerland, the impacts of climate change are categorized into four systems (water, soil, air, and biodiversity), and the adaptation measures is categorized into 13 sectors: water management, natural hazards, agriculture, forest management, energy, tourism, biodiversity management, health (humans and animals), spatial development, housing, traffic, security of supply, and soil protection (Swiss Confederation 2020). From 2022 to 2025, the NCCS-Impacts program 'Decision Support for Dealing with Climate Change in Switzerland: a cross-sectoral approach' is part of the second action plan and has several cross-sectoral and interlinked projects: socio-economic scenarios, global impacts, ecosystem services, human health and animal health, costs of climate change, and critical energy infrastructures. The goal is *'to develop user-oriented climate services as decision support for planning in the field of climate change mitigation and adaptation'* (NCCS 2023). This thesis will contribute to the project 'Costs of climate change impacts in Switzerland with and without successful global climate change mitigation'. The goal of the project is to calculate and compare the costs of climate change in 2060 under the RCP2.6 and RCP8.5 scenarios (NCCS 2023).

2.1.2 Switzerland's Adaptation to Climate Change

In 2020, the Federal Office for Civil Protection (FOCP) which risks endanger Switzerland. Among the most frequent risks are heatwaves, storms, and droughts. While floods are not in the most frequent risks, it is one with the highest aggregated damage costs (FOCP 2020). In order to prevent the most fatal effects of climate change, Switzerland follows a politic trying to reduce greenhouse gas emissions. At the same time, strategies to adapt to climate change are being worked out by the Federal Council and cantonal authorities (FOEN 2012; Swiss Confederation 2014; Thurgau 2022; Zurich 2018). In Switzerland, most of the economic sectors will be impacted by climate change. Agriculture and forestry are sensitive to climate change, and will face changes in crop and plant types due to increasing droughts and heat (Netherer & Hammerbacher 2022; Scheben, Yuan, & Edwards 2016). Adapting crops to the changing climate (e.g. more drought-resistant), can have high benefit-cost ratios (Tröltzsch et al. 2012). As precipitation patterns change, and the intensity of rainfall increases, the urban flood volumes increase non-linearly with climate change (Sun et al. 2021). Additionally, with progressive urbanization, the flood risks increases (Ahiablame & Shakya 2016). The retreating snow cover is the main concern for Swiss tourism, constituting serious challenges to ski resorts (Vaghefi et al. 2021; Vöhringer et al. 2019).

2.1.3 Costs and Damages from climate-related Risks

An increasing number of hot days and nights in Switzerland is predicted for low and moderate emission scenarios, with a much more pronounced effect under RCP8.5 (Vaghefi et al. 2022). Prolonged heat exposure can be fatal, and induce economic costs through loss of labour productivity. Today, the heat-related mortality in Switzerland is around 660 deaths/year while the economic costs are over CHF 665 million. Without adaptation, the mortality is expected to double, and economic losses due to productivity decline are projected to triple by the end of the century under RCP8.5 (Stalhandske et al. 2022). A study in Germany calculated direct costs of € 20.7 billion and median costs of € 35 billion by combining the direct and indirect costs for the heat and drought extreme years in 2018 and 2019 (Jan Trenczek & Oliver Lühr 2022).

Rising temperatures and CO_2 levels increase the population density of invasive insect pests through increased metabolism and consumption resulting in more damage to crops, and yield loss in agriculture (Tonnang et al. 2022). In future climate, heat-adapted crop types (phenological adaptions) are necessary for Swiss wheat breeding to offset heat stress exposure and minimize yield losses (Rogger et al. 2021). Adapting to winter wheat to escape heat stress periods can be beneficial as well (Hayman et al. 2024; Rogger et al. 2021).

In 2023, natural hazards such as floods, debris flows, landslides, and rockfalls caused damage costs of around CHF 75 million which is below the median from 1972-2022 (CHF 103 million, Figure 2.1) (Liechti & Badoux 2024). However, the amount of damage done by the cause of persistent rain is with 67% above average.

2.2 Definitions

2.2.1 Adaptation and Feasibility

A good way to assess adaptation options is to look at the effectiveness and feasibility of the measures (P. A. Williams et al. 2021). The IPCC AR6 defines feasibility as *'the potential for a mitigation or adaptation option to be implemented'* and the practical capability to implement adaptation measures (IPCC 2022). The feasibility assessment considers the economic viability, technical feasibility, institutional capacity, socio-political acceptability, and the environmental impact (IPCC 2022; Singh et al. 2020). A popular way to assess the feasibility of adaptation measures is by identifying adaptation effectiveness, barriers (barrier approach), and enablers (Bar-

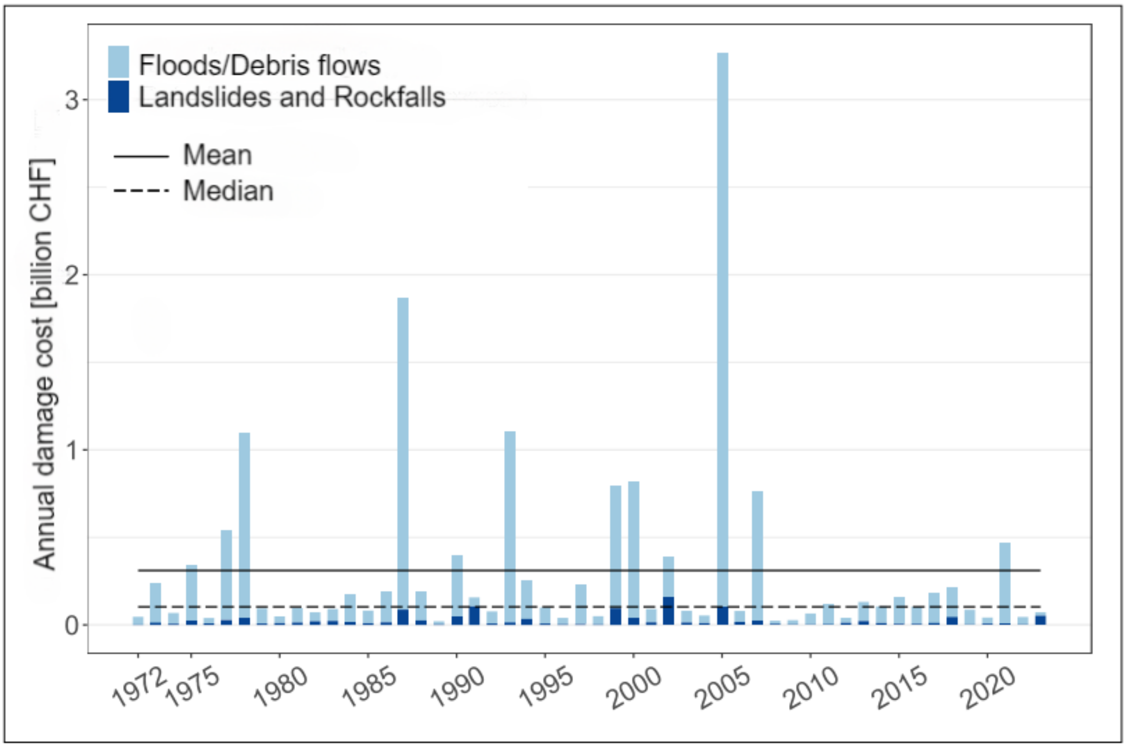


Figure 2.1: Annual damage costs of 1972 to 2023 (adjusted for inflation, based on 2023) with the black line representing the mean and the dashed line the median (Liechti & Badoux 2024, translated).

nett et al. 2015; Singh et al. 2020). The effectiveness will be looked at separately while barriers and enablers are considered in the feasibility assessment through co-benefits, maladaptation, and economic viability.

Effectiveness refers to the extent to which adaptation measures achieve their intended outcomes in reducing vulnerability and enhancing resilience to climate change by mitigating negative effects and leveraging potential positive changes (IPCC 2022; Owen 2020; Singh et al. 2020). The reduction of vulnerability describes how well the measures reduce the susceptibility of communities and systems to climate impacts. The enhanced resilience increases the system's ability to cope with and recover from climate impacts (IPCC 2022).

2.2.2 Costs of Climate Change

The costs of climate change impacts are multidimensional and can become very large. Suitable adaptation measures can significantly reduce or even prevent expected damage costs (Hirschfeld et al. 2021). Hence, knowing the costs of adaptation measures is important to get a benefit-cost ratio. The following terminologies on the classi-

fication of costs from natural hazards are based on Parker, Green, and Thompson (1987) (cited in Kreibich et al. 2014). Hirschfeld et al. (2021) uses similar terms.
Direct costs result form the direct physical impact of the natural hazard on humans, economic assets, buildings, agricultural products, stocks, vehicles, and other objects. Areas affected by the hazard experience **business interruption costs** when workplaces are destroyed or inaccessible or if water scarcity reduces production. Furthermore, **indirect costs** affect economic entities not immediately but with a time lag ,and they can occur either inside or outside the hazard area. They include consequential costs of infrastructure disruption, value-added losses due to production interruptions, ecological damages impacting value creation, employment, and satisfaction, as well as social effects impacting social harmony.
Each category described above can be tangible or intangible (see Table A.1). **Tangible costs** can be measured in monetary terms while **intangible costs** are damages to people, goods, and services which are difficult to monetise.

Implementing adaptation solutions generate different costs according to the nature of the measure. Some measures, such as awareness raising campaigns for heat-related risks in summer months, need annual investments to keep the campaign running while structural implementations only need one-time investments. By comparing the costs of the adaptation measures and their reduction of damages with the costs of climate change impacts without adaptation, benefit-cost calculations can be done (Tröltzsch et al. 2012; Vöhringer et al. 2019).
In this thesis, only costs of adaptation measures are considered since including the damage costs as well would go beyond the scope of the thesis.

2.2.3 Risk Analysis

The risk analysis answer the question of what could happen by qualitatively and quantitatively assessing the assets at risk, their exposure and vulnerability (Kienholz et al. 2004). Huggel et al. (2013) defines risk as a function of the probability of occurrence of an extreme event and its associated consequences. The later is a function of the intensity of the event, exposed assets, and vulnerabilities.

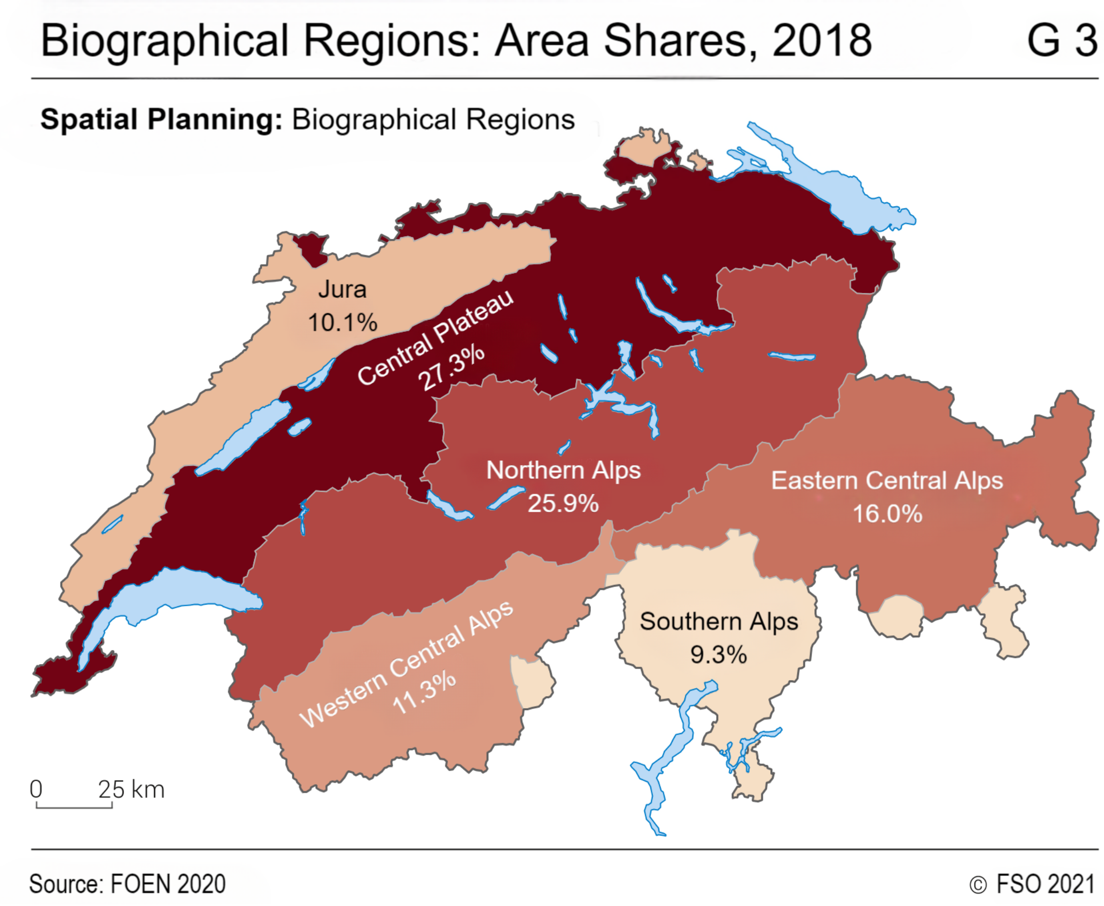
3. Study Area

Switzerland lies in Central Europe and is characterized by distinct features such as the Jura, the Alps, and the Central Plateau. With an area of 41'291 km^2, it is a small country (FSO 2024c). Nevertheless, Switzerland can be divided into six major regions (Figure 3.1). The Jura mountain range extends from the northeast to the southwest along the border in the northwest of Switzerland. The Jura makes about 10% of Switzerland's area. The Alps are the most dominant feature covering around 60% of the area and extends from west to east. There are large differences in the elevation which ranges from 600 m asl to over 4000 m asl (highest peak: Dufourspitze 4'634 m asl). The mean elevation of the Swiss Alps is approximately 1700 m asl. The Alpine region can be divided into four parts: Northern Alps, Western Central Alps, Southern Alps, and Eastern Central Alps (FSO 2021). The Western Central Alps consists mainly of the Valais. The Southern Alps, also known as Southern Switzerland, contains of Ticino, and small parts of Valais and Grisons. Most of the canton of Grisons is part of the Eastern Central Alps which also entails parts of Uri and Glarus. The largest fraction of the Alps is the Northern Alps with 25.9% of Switzerland's area. This part of the Alps stretches all the way from the eastern to the western border. In between the Swiss Alps and the Jura lies the Swiss Plateau. It is a southwest to northeast oriented basin stretching from Lake Geneva to Lake Constance with a mean elevation around 600 m asl. A third of the population lives in the Swiss Plateau, despite half of the area being covered by agricultural fields. A total of 35% of the area of Switzerland is used as agricultural area, while settlements only take up 8% (FSO 2024a).

Looking at the climatic conditions, the Alps act as a border. In the south, more Mediterranean conditions prevail, and a temperate semi-continental climate in the northern parts. The Northern and Southern Alps receive the most precipitation while the Western Central Alps receives the least. The air temperature strongly depends on the location. At low altitudes, the coldest monthly average ranges from -0.5 to 3.5°C while the warmest month has a mean of 18 to 22°C (Fallot 2021).

This diversity in topography and climate showcases that the consequences of the climate change will differ in each region. Therefore, looking at the state structures is necessary. The highest authority is the Federal Council, which in 2012 defined the framework for Switzerland's strategy for the adaptation to climate change (FOEN 2012). The federation is divided into 26 cantons, each having their own cantonal government with quite a lot of agency. The canton is further divided into municipalities, which are responsible for the social services, spatial planning and construction, infrastructure, and environmental protection.

The database is built with the federal structure in mind dividing the federal, cantonal, and municipal responsibilities.



Source: FOEN 2020

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Figure 3.1: Regions and area shares in Switzerland (FSO 2021, translated).

4. Methods

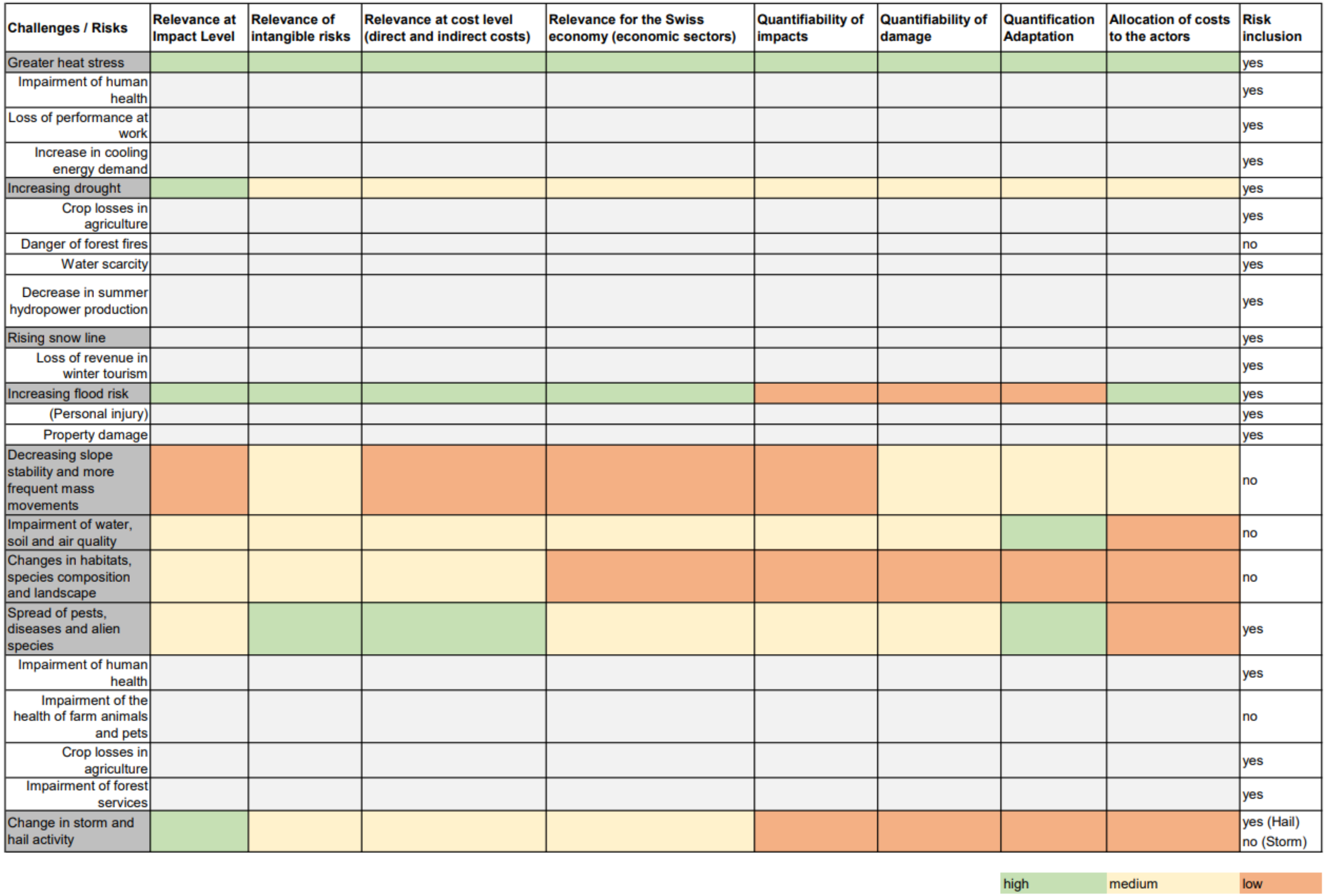
4.1 Literature Review

To build a comprehensive database on climate adaptation measures, it is important to consider literature of different origin and type. Hence, the literature review process becomes rather important. The increasing demand for climate adaptation solutions leads to an increasing amount of literature. For the literature research, a number of tools were used. First and foremost, Google scholar acted as the primary tool to look for literature. Elicit and Researchgate were used as well. Additionally, in the age of artificial intelligence (AI), Researchrabbit helped finding literature linked to the one's already gathered. Consensus, an other AI tool, served as a tool to get a first impression and summary of the literature. However, most of the literature found this way was written by scientists without the inclusion of practitioners. As Howarth and Viner (2022), it is important to have practitioners contribute to enhance the credibility and salience. In Switzerland, there is a mandate for a coordinated approach to adapt to the impacts of climate change. Hence, many cantons have commissioned adaptation and mitigation plans (e.g. Zurich 2018). In addition, federal offices also engaged in creating plans to look into mitigation and adaptation measures. The Federal Office for the Environment (FOEN) with its action plan 2020-2025 also included multiple solutions to adapt to climate change (Swiss Confederation 2020). The Federal Office of Public Health (FOPH) created a heat action tool box which is provided to the cantons to improve their response to heat related challenges. As a result, there is number of grey literature (mostly white papers) looking into adaptation measures for Switzerland, created by federal and cantonal administrations. Most of these federal and cantonal plans were created by consulting firms. Some of the plans did their own literature review and added an extensive literature list including mostly papers from Switzerland (e.g. Thurgau 2022).

4.2 Risks and Challenges

In a first step, the most important risks and opportunities for Switzerland through climate change were identified. The meaning of the opportunities were defined in the strategy for adaptation to climate change in Switzerland (FOEN 2012, Chapter 2). The basis of the risk analysis is a Switzerland-wide synthesis on climate risks (Köllner et al. 2017). About 360 experts from science, business, and administration helped creating the analysis of climate-related risks in Switzerland. Hereby, eight case studies covering the six major regions in Switzerland (Jura, Swiss Plateau, Prealps (border region of the Swiss Plateau and the Northern Alps), Southern Switzerland, and large agglomerations) were done to identify the risks and opportunities for Switzerland in 2060. Then, the results were transferred to all regions of Switzerland. In the synthesis report, 12 risks and around 30 opportunities were found which summarise the risk landscape for Switzerland. Now, those risks and opportunities can be used for further developments of the Confederation's adaptation strategy.
For this thesis, the project team qualitatively assessed and selected the most important risks and opportunities based on various criteria (e.g relevance at impact level, relevance at cost level, relevance for the Swiss economy; Figure 4.1). The selection was presented to the NCCS and the FOEN. In the end, the final list was presented to stakeholders. Due to their feedback, the change in hail activity was included.

In the database, the opportunities group and separate the risks into thematic units such as the greater heat stress. Greater heat stress (opportunity) impacts the human health, loss of performance at work, and the cooling energy demand (risks). Together, the opportunities and risks are used to create an ID to which the adaptation measures are linked.
Table 4.1 shows the final opportunities and associated risks used for the adaptation database.



Challenges / Risks	Relevance at Impact Level	Relevance of intangible risks	Relevance at cost level (direct and indirect costs)	Relevance for the Swiss economy (economic sectors)	Quantifiability of impacts	Quantifiability of damage	Quantification Adaptation	Allocation of costs to the actors	Risk inclusion
Greater heat stress	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	yes
Impairment of human health									yes
Loss of performance at work									yes
Increase in cooling energy demand									yes
Increasing drought	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	yes
Crop losses in agriculture									yes
Danger of forest fires									no
Water scarcity									yes
Decrease in summer hydropower production									yes
Rising snow line									yes
Loss of revenue in winter tourism									yes
Increasing flood risk	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟩	yes
(Personal injury)									yes
Property damage									yes
Decreasing slope stability and more frequent mass movements	🟧	🟨	🟧	🟧	🟧	🟨	🟨	🟨	no
Impairment of water, soil and air quality	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟧	no
Changes in habitats, species composition and landscape	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	no
Spread of pests, diseases and alien species	🟨	🟩	🟩	🟨	🟨	🟨	🟩	🟧	yes
Impairment of human health									yes
Impairment of the health of farm animals and pets									no
Crop losses in agriculture									yes
Impairment of forest services									yes
Change in storm and hail activity	🟩	🟨	🟨	🟨	🟧	🟧	🟧	🟧	yes (Hail) no (Storm)

🟩 high 🟨 medium 🟧 low

Figure 4.1: Decision support matrix to define the risks looked at in the adaptation process in Switzerland. The opportunities are marked with a grey background. The risks are white.

4.3 Database

After deciding which risks to look at, the building of the database came next. The database is based on the literature review and the expert assessment. After a first draft, the project team discussed the current state of the measures and appropriate adjustments were made. To include practitioners, a stakeholder workshop was organised where different organisations and corporations took part. They were asked to provide their insight on possible adaptation measures and what they think is needed. There were multiple rounds of literature review and review process within the expert team to finalize the current version of the database.

Each separate measure has its own title and description. In the description, further explanation and examples are provided for the end-user. As there are different categories (see Subsection 4.3.3), some adaptation solutions are mentioned multiple times since they act on different administration levels or in different risks.

To give an overview of the most used type of measure, a word cloud with the measure titles is generated. This was done with Python (version 3.9.12), and the package 'WordCloud' (version 1.9.3). Furthermore, figures with the number of measures per risk, actor, target audience, measure package, and measure category provide insight to who and what can be done. Those figure are created with the 'seaborn' package (version 0.13.2).

4.3.1 Expert Assessment

During the entire process of the literature review, the building of the dataset, and the feasibility assessment, an expert group worked together. Each member specializes in a slightly different field, background, and experience. The experts used their knowledge and experience for verifying and refining the approach during the construction of the database and the feasibility assessment.

4.3.2 Translation

As the project is from the NCCS, the final database was in German, but had some French and English parts as well. For this thesis, however, the list of measures must be entirely in English. For the translation the AI tool 'AJELIX' was used in combination with an API from Google translate. This allowed the AI tool to automatically detect the language and translate each entry to English. A personal revision of the translation was done to correct errors and possible changes in the meaning. Only little adjustments had to be done in the aftermath.

4.3.3 Elements of the Adaptation Measure List

The database not only lists the adaptation measures but also describes various parameters (e.g. range of effect) in different columns. The columns preceding the measure title group the solutions into categories based on the risk addressed, the actor, the target audience, the measure packages, and the category of the measure. Subsequently, various parameters are listed: the perimeter, range, and type of effect, quantifiability, costs and avoided damage costs, economic impact, robustness, sustainability, co-benefits, flexibility, and maladaptation.

The **MeasureID** assigns each solution a unique identifier for clear identification. The ID is composed of abbreviations from the actor, the target audience, the package of measures, and the RiskID, followed by ascending numbering to distinguish otherwise identical IDs (Figure 4.2).

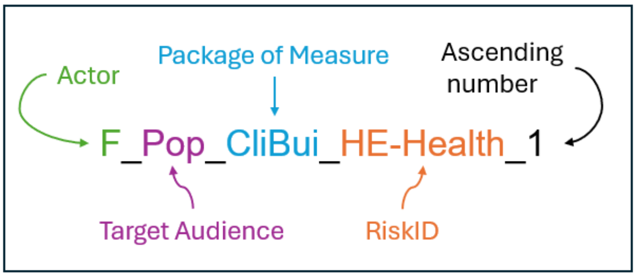


Figure 4.2: The composition of the MeasureID.

The **RiskID** connects the opportunity and the risk which is addressed by the measure. The ID is created with an abbreviation of the opportunity and keyword of the risk (see Table 4.1).

The **Actor** (Table 4.2) defines which political or societal level implements the measure in order for it to be effective. There are six different actors stated of which three are from within the governmental structure (Federal Government, Cantonal level, and Municipal level). Then, corporations are needed to implement certain measures as well as private households and individuals (collectively as 'Private').

Table 4.1: Opportunities, corresponding risks, and the RiskID.

Opportunity	**Risk**	**RiskID**
Greater heat stress	Impairment of human health	HE-Health
Greater heat stress	Increase in cooling energy demand	HE-Cool
Greater heat stress	Loss of productivity at work	HE-Prod
Increasing risk of flooding	Personal and property damage	FL-Dmg
Rising snow line	Loss of income from winter tourism	SL-Yield
Spread of harmful organisms, diseases and alien species	Impairment of human health	HO-Health
Spread of harmful organisms, diseases and alien species	Harvest loss in agriculture	HO-Agri
Spread of harmful organisms, diseases and alien species	Impairment of forest services	HO-Forest
Increasing drought	Harvest losses in agriculture	DR-Agri
Increasing drought	Decrease in summer hydropower production	DR-Elec
Increasing drought	Water scarcity	DR-Water

Table 4.2: List of the actors and target audiences.

Actors
Federal Government (Federal Offices)
Cantonal level (Cantons)
Municipal level (Municipalities)
Universities
Corporations
Private

Target Audiences
Entire population
Part of the population
Vulnerable groups
Civil society (e.g. NGOs)
Public hand (Cantons and municipalities)
Corporations

In the **Target audience** (Table 4.2), the beneficiaries of each adaptation solution is stated. Measures can be aimed at the entire population, or specifically at parts of the population such as skiers or homeowners. Additionally, some measures reduce impacts on vulnerable groups (e.g. people with preconditions). Most measures taken at corporation level are also aimed to help corporations reduces losses or help protecting employees. Other beneficiaries are the public hand (cantons and municipalities) as well as the civil society (e.g. NGOs).

Furthermore, the **Measure category** groups the measures into types of activity needed for implementation. Nine different categories were chosen which go from "Research" and "Legal requirements" to "Structural implementation". A full list of the used categories and their description can be found at Table 4.3.

Table 4.3: Measure categories with their explanation.

Measure category	**Description**
Legal requirements	Requirements and approvals for the implementation of specific measures
Research	Research and development of new technologies or approaches
Concept and strategy	Development of fundamentals, studies, concepts and strategies
Structural implementation	Measures involving investments in construction
Process-oriented measures	Measure that optimize processes
Technical implementation	Measures that integrate technical facilities
Financial support	Financial or substantive support for measures (e.g. pilot projects, funding programs, etc.)
Communication	Measures to inform, raise awareness, and communication with specific target audiences
Monitoring and early warning	Measures to establish monitoring and/or early warning systems

The **Measure package** gives a superior meaning to the measures and briefly describes where the measure comes across. A grouping of the adaptation measures in to packages enables to sort the list according to the need you want to address (e.g. irrigation). There are 24 different packages each related to one of the risks. In Table 4.4 all packages and their respective risk are listed.

Table 4.4: Measure packages and corresponding risks.

Measure Package	Risk
Climate-adapted buildings	HE-Health, HE-Cool, HE-Prod
Local climate	HE-Health, HE-Cool, HE-Prod
Protecting the population from heat	HE-Health
Protecting employees from heat	HE-Prod
Risk-based spatial planning	FL-Dmg
Property protection	FL-Dmg
Water retention	FL-Dmg
Prevention of natural hazards	FL-Dmg
Flood protection	FL-Dmg
Artificial snowmaking	SL-Yield
Adapting tourism offer	SL-Yield
Handling food	HO-Health
Protection against infectious diseases	HO-Health
Prevention of pests	HO-Agri, HO-Forest
Climate-adapted cultivation	HO-Agri
Control of pests	HO-Forest
Climate-adapted cultivation	DR-Agri
Irrigation	DR-Agri
Risk protection for agriculture	DR-Agri
Prevention of drought	DR-Agri
Ensuring hydropower production	DR-Elec
Reduction of water consumption	DR-Water
Ensure water supply	DR-Water

Further elements in the adaption list are the **perimeter of effect**, the **range of effect**, and the **type of effect**. The first one describes the geographical region in which the measure will be implemented such as the Alps or the Swiss Plateau. The orientation for this classification comes from Köllner et al. (2017). The range of effect defines the scope of the measure, and answers if the measure will be implemented nationally, regionally or locally. The type of effect, expresses how the measure works, meaning if it will reduce physical damage, or reduces yield loss, etc. However, these parameters are not yet fully developed and will not be used.

For further analysis, the **quantifiability of the effect** and the **quantifiability of the cost** of each measure is analysed. In a first step, a simple determination with a 'yes' or 'no' was done. In a next step, a series of parameters are provided for the analysis of monetary effects of the measures, for example, the annual investment and operating costs, and the avoided damage costs. However, this thesis does not go into the details of these costs and related parameters, as the cost assessment is only done with certain measures (see Section 4.4).

The parameters effectiveness, robustness, sustainability, financial viability, flexibility, co-benefits, and maladaptation are used for the analyses of feasibility and effectiveness, hence described in Subsection 4.3.5.

4.3.4 Co-occurrences and Associations

To highlight patterns within the database, co-occurrence figures are created. Those figures show the count of measures per risk and actor, or other combinations. A Chi-square test of independence is used to determine if there is a significant association between pairs of the categorical variables. For this, the 'chi2_contingency' function from 'scipy.stats' (version 1.13.1) was used. A heat map is created showing these associations between the variables.

4.3.5 Feasibility and Effectiveness

The database uses a number of variables which can be used as proxies for the assessment of the feasibility and the effectiveness. For each variable, a qualitative score with three levels (low, medium, high) for their strength and approval was given and discussed in an expert assessment. A score of low, medium, or high is in line with previous studies (Bednar-Friedl et al. 2022; Singh et al. 2020). For the analysis, the qualitative scores get transferred to numerical scores of 1 (=low), 2 (=medium), and 3 (=high).
There are two metrics in the dataset to assess the effectiveness of a measure. First, there is the **Effectiveness** which is a qualitative assessment of how effective the measure is to reduce the risk. This reduction of the risk is in line with the definition for the effectiveness by IPCC (2022), Owen (2020), and Singh et al. (2020) which is to reduce risks and vulnerabilities and improve the resilience. The second metric used in the effectiveness assessment is the **Robustness**. The robustness is a

qualitative assessment of whether the measure has a positive impact under different climate scenarios. Hence, a measure with a high robustness can be used in all RCP emission scenarios. In Singh et al. (2020), enhancing the resilience to climate change is in their definition for effectiveness and a way to achieve the intended outcome. The robustness and effectiveness are reported separately. For an overall assessment, the scores for the effectiveness will be grouped by the risk type, the actors, and the measure category.

For the feasibility assessment, the database contains variables which resemble the various dimensions (economic, technical, institutional, socio-political, and environmental factors) mentioned by IPCC (2022) and Singh et al. (2020) to describe feasibility.
First, there is the **Sustainability** which assess if the measure best takes the balance of the society, economy, and ecology into account. Does the measure, therefore, enable a lasting, environmentally and socially just development of society? This variable represents the socio-political acceptability as well as the environmental factor. The **Financial viability** describes whether the measure can be implemented at a reasonable cost, and examines the dimension of the economic viability. Another variable, which alludes the economic dimension, is the **Flexibility**. It describes the economical effort needed to modify the measure. Here, a low score means that the cost to modify the measure is high. For the quantitative meaning of low, medium, and high costs, the expert team oriented themselves on the cost dimensions from FOEN (2024) where "low" are costs up to CHF 20 million, "medium" is CHF 20 to 100 million, and "high" means more than CHF 100 million. To assess if the measure has positive side effects on the environment, society, or for the implementing organisation apart from the adaptation to climate change, the database uses the variable **Co-benefit**. The variable addresses the environmental, and socio-political dimension. The **Maladaptation** is the opposite of the co-benefit, and tells us whether the measure negatively effects the environment, society, or the implementing organisation. It addresses the socio-political acceptability.
Table 4.5 lists each variable and the feasibility dimension according to Singh et al. (2020). After transforming the qualitative scores of low, medium, high to numerical values from 1 to 3, the scores for all five variables are taken together to generate a mean and standard deviation (SD). Then, the scores are grouped by the risk, actor, and measure category.

Table 4.5: Variables in the database and their respective dimension for the feasibility assessment.

Variable	Feasibility factor
Sustainability	Socio-political acceptability and environmental factor
Financial viability	Economic factor
Co-benefits	Socio-political acceptability and environmental factor
Flexibility	Economic factor
Maladaptation	Socio-political acceptability and environmental factor

4.4 Cost Assessment

A selection of specific adaptation measures was used for the cost assessment. The decision to choose a measure was based on the quantifiability of the effect and the quantifiability of the costs. Both factors have to be answerable with a 'yes' for the cost assessment. The judgement, if a measure is quantifiable or not, was done within the expert group.

The costs for the measures were collected from different sources, including web-pages (e.g. Building energy certificate of the cantons (GEAK)), grey literature and white papers as well as scientific research. To be able to compare the costs, they have to be brought to the level of 2023 by an inflation compensation (accounting costs of 2023). The inflation calculator (https://lik-app.bfs.admin.ch/) by the Federal Statistical Office (FSO) allows to quickly adjust the costs according to their relative height for 2023 (FSO 2024b). To picture the future costs, a discount rate of zero will be assumed according to the guidelines of the project.

In the cost analysis, a distinction was made between one-time investments and annual costs. Often, only one or the other was found. For some measures, only cost estimates from similar projects and topics were found, such as for awareness-raising campaigns or funds. One example is the cost of financial support for specifications for climate-adapted buildings (MeasureID: Ct_Pop_CliBui_HE-Cool_1), which is derived from the cantonal plan of Ticino for the replacement of fossil-fueled heating systems.

For the figures of the cost analyses, three measures were removed as they are all about the cooling and thermal protection of buildings with different methods. Hence, using all of them would skew the costs, as only one measure will be applied per building. There are still two measures in the database of the cost assessment to cover the "Summer thermal protection" for corporations and private households. The removed measures are listed in the appendix (Table A.2).

4.4.1 Extrapolation to National Level

The cost assessment aims to estimate the costs of climate change adaptation for Switzerland. Hence, the costs need to be on a national level. However, most costs come from federal, cantonal, or municipal climate adaptation plans, and are on the cantonal level. In dependence of the type of measure, the interpolation to a Swiss-wide cost was done on different metrics. The used metrics are relative to the population, parts of the population (e.g. employees), total area, settlement area, agricultural area, number of buildings, economic strength (GDP), and number of people working in tourism (to represent the economic gains through tourism). The used sources are all from the FSO or the Federal Finance Administration (FFA), mostly by using their Statistical Atlas of Switzerland (https://www.atlas.bfs.admin.ch/) (FFA 2023; FSO 2023a, 2023b, 2023c).
Below is an example calculation for the measure "Information and recommendation on protection against heat (FOPH)" (MeasureID: F_Pop_ProtPop_HE-Health_2. Figure A.8 shows a couple of examples of the interpolation.

$$\text{Investment costs 2018:}\ \text{CHF } 10'000 \tag{4.1}$$

$$\text{Inflation increase to 2023:}\ \text{CHF } 10'521 \tag{4.2}$$

$$\text{CH indicator:}\ 8'815'385 \tag{4.3}$$

$$\text{Cantonal indicator:}\ 1'579'967 \tag{4.4}$$

$$\text{Interpolation factor:}\ \frac{8'815'385}{1'579'967} = 5.579 \tag{4.5}$$

$$\text{Investment cost extrapolated:}\ \text{CHF } 10'521 \times 5.579 = \text{CHF } 58'702 \tag{4.6}$$

5. Results

In this section, key numbers and figures about the database are presented to address the research objectives and questions. The two main objectives of this thesis are to build a comprehensive database of climate adaptation measures for Switzerland and to assess their feasibility and effectiveness through proxy indicators. Further, the costs of implementation for a selection of the adaptation measures across Switzerland are calculated.

5.1 General Characteristics of the Database

This database is the first of its kind on climate adaptation measures in Switzerland which includes measures across multiple risks, indicators of feasibility, exposure and costs. The measures to build the database were collected in an extensive literature research process coupled with multiple rounds of expert discussions. Many measures come from grey literature such as the cantonal plans in Switzerland. Since the adaptation database is for practitioners, federal, cantonal, and municipal authorities as well as for the public hand, exchanges with them were done in stakeholder workshops. They were able to provide feedback to the chosen risks, got a glance at a draft of the adaptation database, and gave their own feedback. Through this process, additional measures were added.

In total, the database comprises of 236 adaptation measures distributed over five opportunities and eleven risks (see Table 4.1). The opportunities are the superior order for the risks. The database assigns the measures to actors which have to act and implement the measure to get the effect. The target audience tells the reader who are the beneficiaries of the measure. The measure packages is a grouping of measure going towards the same goal. For example, the "Climate-adapted buildings" package groups measures with the aim to reduce heat in buildings by installing cooling systems or enhance the thermal insulation. Within the measure category,

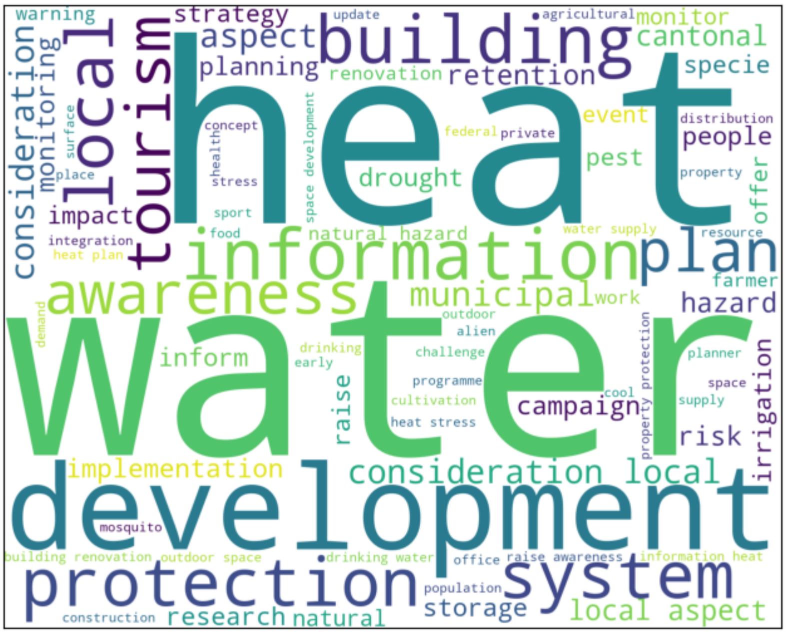


Figure 5.1: Word cloud created from the most mentioned one or two word expressions of the 236 measure titles.

the type of the adaptation solution is described and grouped. "Installing cooling systems" is a technical implementation while "Thermal insulation" is a structural measure. For each measure, a measure title and a description with examples are provided. The measure title provides an overview of what the adaptation solution achieves.

Grouping the measures into different risks and actors has the consequence that certain measures are mentioned multiple times since they can be implemented by different players or affect multiple risks. Such a measure is the "Installation of cooling systems" which can be done by corporations to protect employees and reduce loss of productivity at work. Simultaneously, private households can also install cooling systems to enhance living conditions during heat.

The word cloud in Figure 5.1 is created out of the measure titles using the most frequent one- to two-word expressions. "Water" and "heat" are the most dominant key words. There are three different risks combating the effects of heat and drought (HE-Cool, HE-Health, HE-Prod). Developing new technologies or federal, cantonal, and municipal health plans are prevalent in the database. Further, measures about informing the population are frequent as "information" and "awareness" belong to the most used words. "Protective systems" and "buildings" give an insight on what and where measures should be applied. Using the 105 unique measures by removing the duplicates from different actors or risks, the word cloud looks fairly similar (Figure A.1).

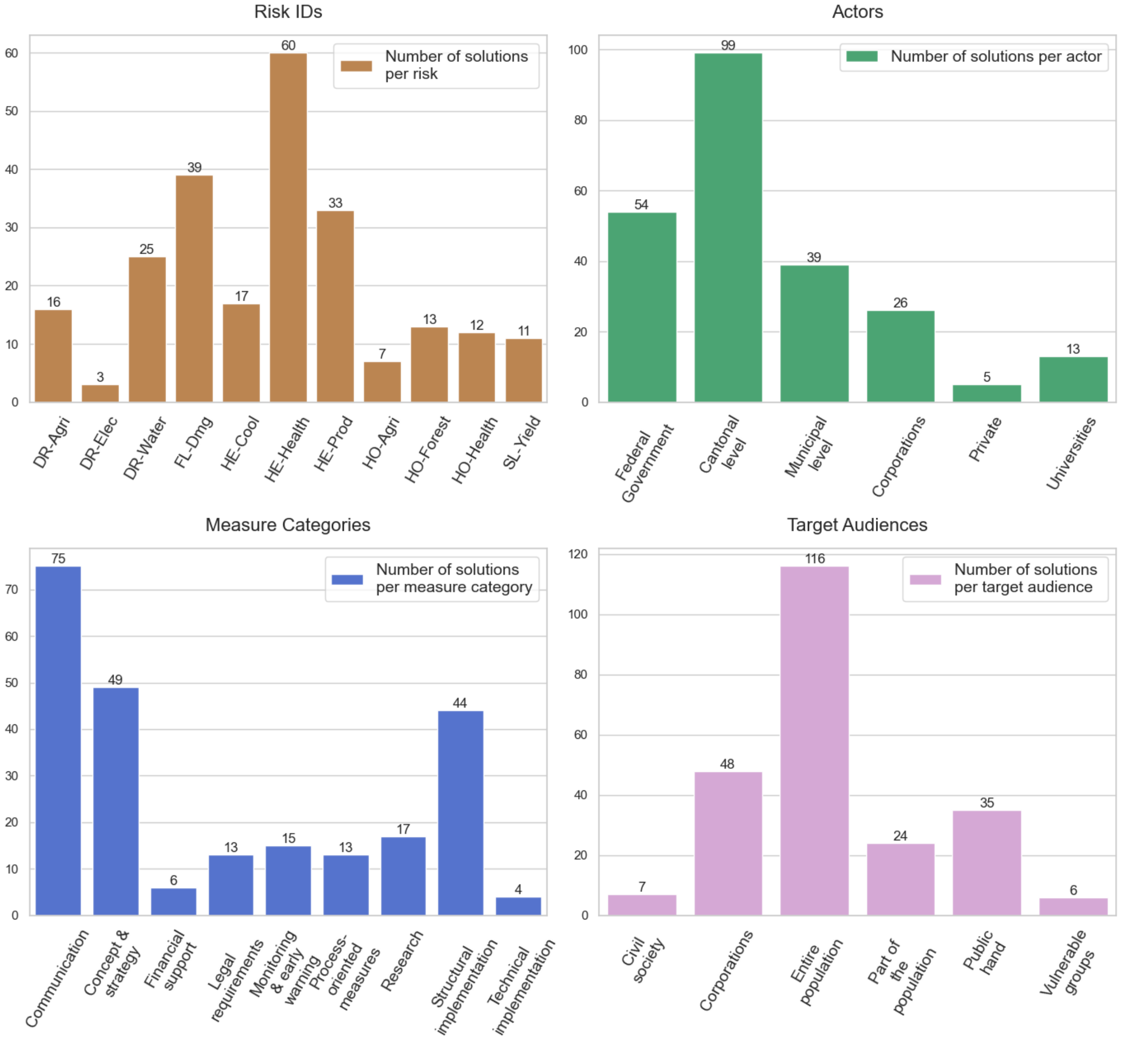


Figure 5.2: Number of solutions for each risk, actor, measure category and target audience.

Most of the measures are aimed at heat-related risks (110), followed by drought (44), and the FL-Dmg (39) (Figure 5.2). Measures aimed at mitigating the "Impairment of human health" (HE-Health) constitutes by far the highest number of measures.

There are 54 measures to be enacted by the Federal Government, 99 measures assigned to the "Cantonal level", 28 measures designated for "Corporations", and only 5 measures for private households and individuals.

Even though, a large share of the measure should be implemented by governmental authorities, only 13 measures adapt "Legal requirements". However, "Communication" (99) and "Concepts and strategy" (49) make up the largest categories since awareness campaigns and health or emergency plans are within governmental responsibilities.

For almost half of the measures, the entire population is the beneficiary. As most of the measures are from governmental authorities, this seems to be a good fit. There are only six measures looking to better protect vulnerable groups.

Looking at the measure packages in Figure 5.3, "Climate-adapted buildings" and "Protecting the population from heat" are the most prevalent sectors in the database. This relates to the number of heat risks. Other heat-related packages such as the "Local climate" and "Protecting employees from heat" are also among the most mentioned solutions. With only two measures in "Artificial snowmaking", winter tourism only has very limited options.

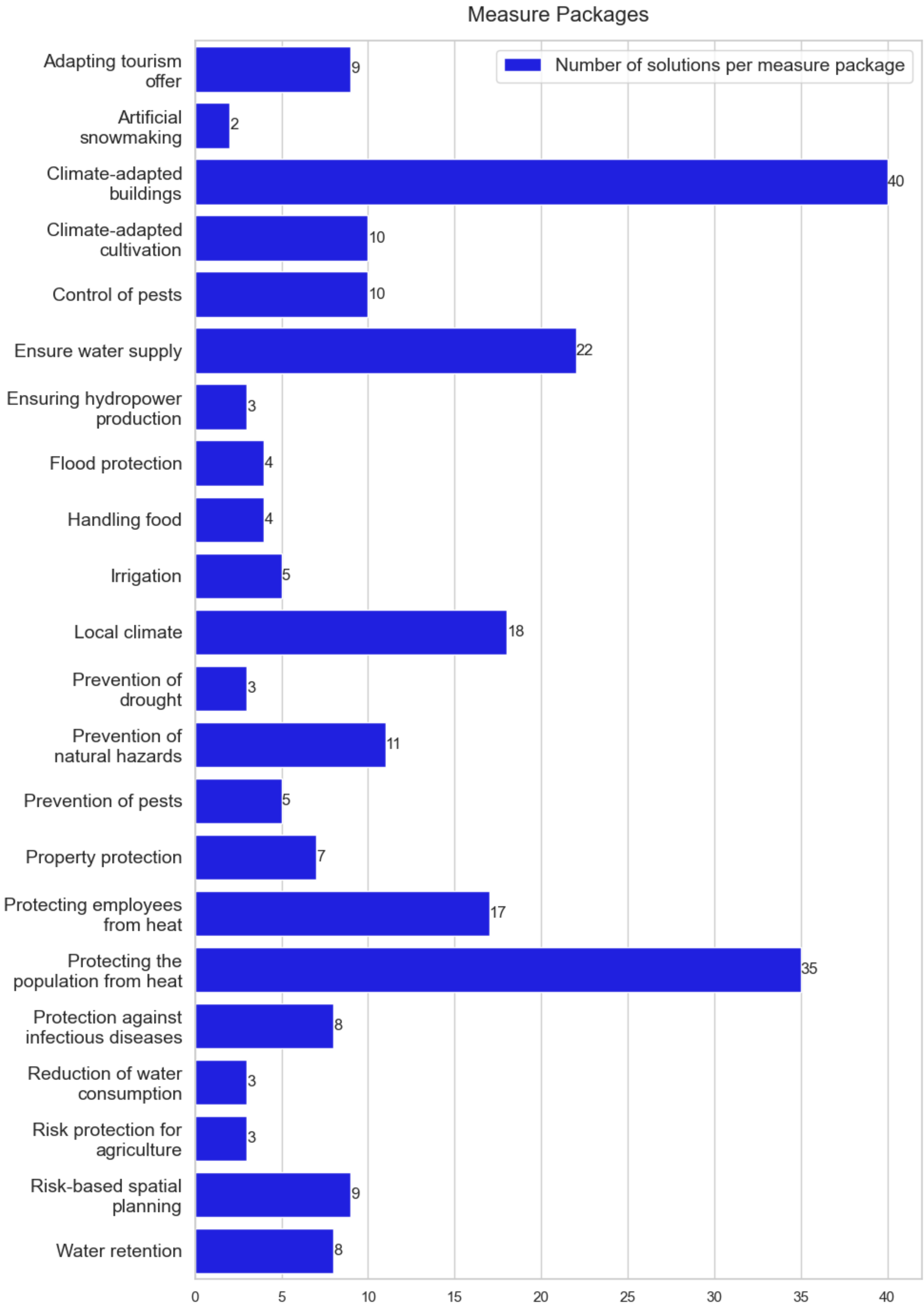


Figure 5.3: Number of solutions per measure package.

5.1.1 Co-occurrences

The heat map for the "RiskIDs" and "Actors" illustrates the involvement in addressing the climate risks by representing the frequency of the measures (Figure 5.4). The "Federal Government" is notably involved in the "Increasing risk of flooding" (FL-Dmg), and "Impairment of human health" (HE-Health), and "Loss of productivity at work" (HE-Prod) (9 measures each). The highest involvement is shown by the "Cantonal level" with significant co-occurrences in addressing HE-Health (31 measures), and FL-Dmg (14 measures). With 12 measures each, "Water scarcity" (DR-Water) and HE-Prod, are significantly present on the "Cantonal level". The "Municipal level" has considerable involvement in HE-Health (13 measures) and in FL-Dmg (11 measures). "Corporations" primarily show engagements in preventing HE-Prod (6 measures), "Loss of income from winter tourism" (SL-Yield) (5 measures), and "Harvest losses in agriculture" (DR-Agri, 4 measures). The private sector has minimal involvement across all risks, with a slight presence in the FL-Dmg (2 measures). "Universities" show engagements in HO-Forest (3 measures), HE-Health (3 measures) and from HO-Health (2 measures).

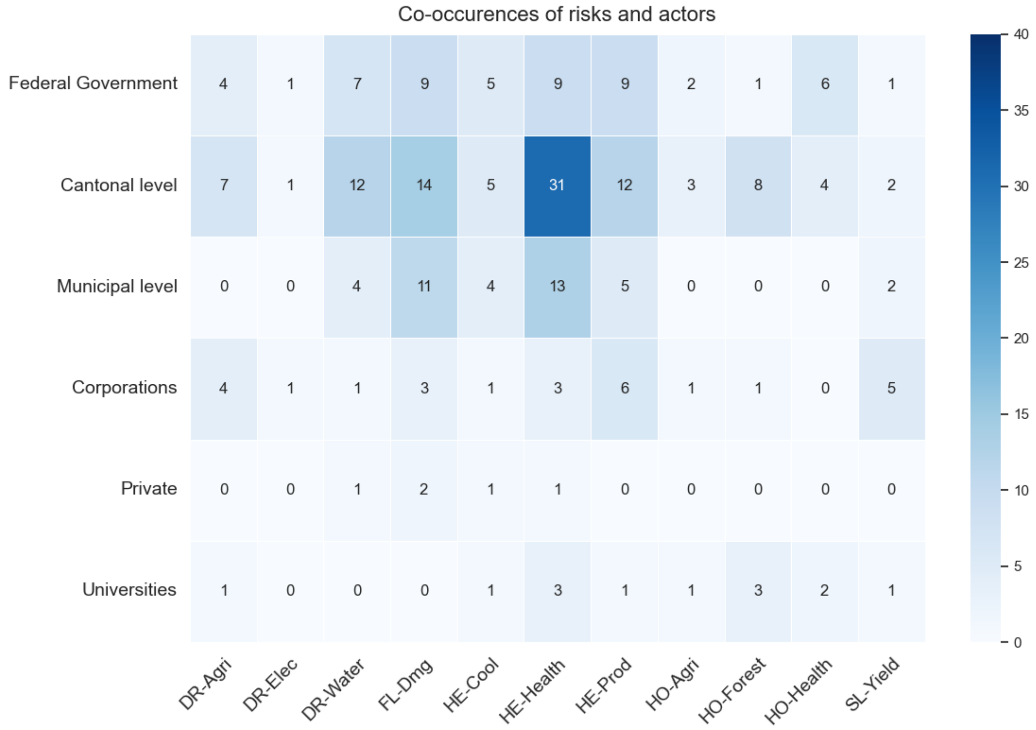


Figure 5.4: Co-occurrences of measure by the RiskID and Actors. The co-occurrences show the number of measures in each combination.

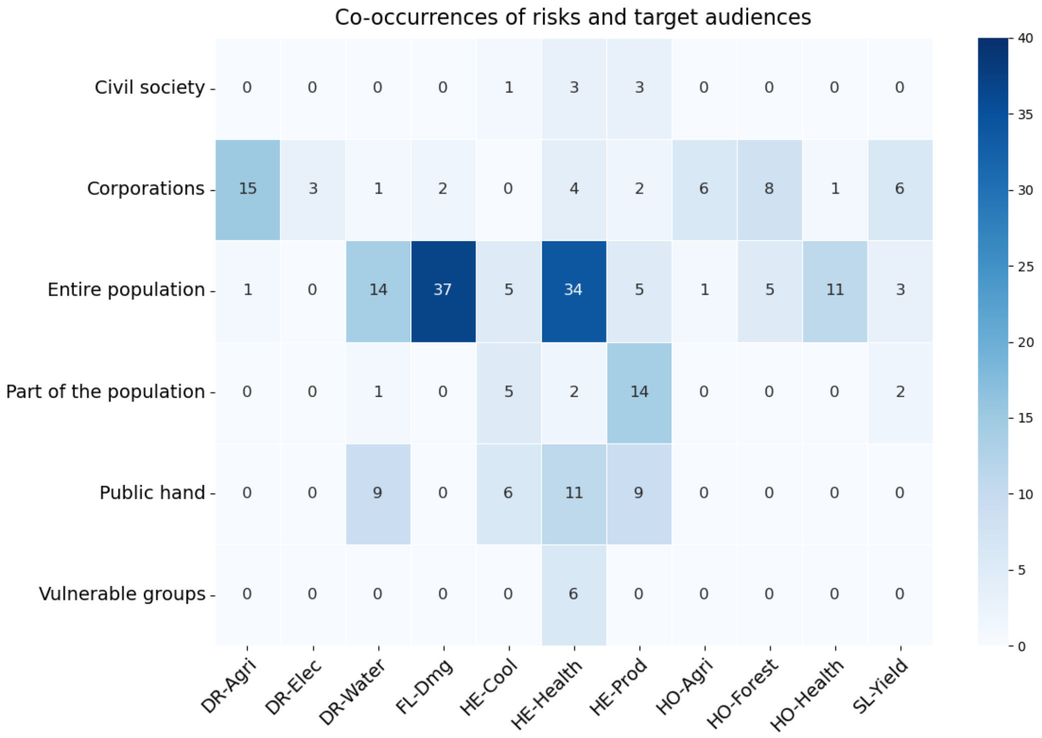


Figure 5.5: Co-occurrences of measure by the RiskID and Target audience. The co-occurrences show the number of measures in each combination.

Figure 5.5 shows a heat map illustrating how different target audiences benefit from climate adaptation measures addressing specific climate risks. The entire population benefits the most across all target audiences with 116 measures addressed to them. Significant are measures to prevent flood damages (FL-Dmg, 37 measures), and to reduce heat stress (HE-Health, 34 measures). Further, "Reducing water scarcity" (DR-Water, 14 measures) and "Impairments from human health through harmful organisms" (HO-Health, 11 measures) are also aimed at the entire population. This indicates that these risks are considered to impact the general population broadly. The second-highest number of measures, totaling 48, are designed for "Corporations" to benefit from. Considering the significant implications for economic and ecological operations, many measures target risks such as "Harvest loss in agriculture due to drought" (DR-Agri, 15 measures) and "Harmful organisms or pests" (HO-Agri, 6 measures), "Loss of income from winter tourism" (SL-Yield, 6 measures), and "Impairment of forest services" (HO-Forest, 8 measures). To increase the resilience of the public sector, 35 measures are target at public entities. HE-Health (11 measures), DR-Water (9 measures), HE-Prod (9 measures), and HE-Cool (6 measures) are the targeted risks. Only 24 measures benefit a specific part of the population. 14 measures in "Loss of productivity at work" (HE-Prod) indicates a particular vulnerability to this risk. Civil society and vulnerable groups show minimal direct benefits across all risks with a total of 7 and 6 measures, respectively. Only HE-Health is addressed directly for vulnerable groups.

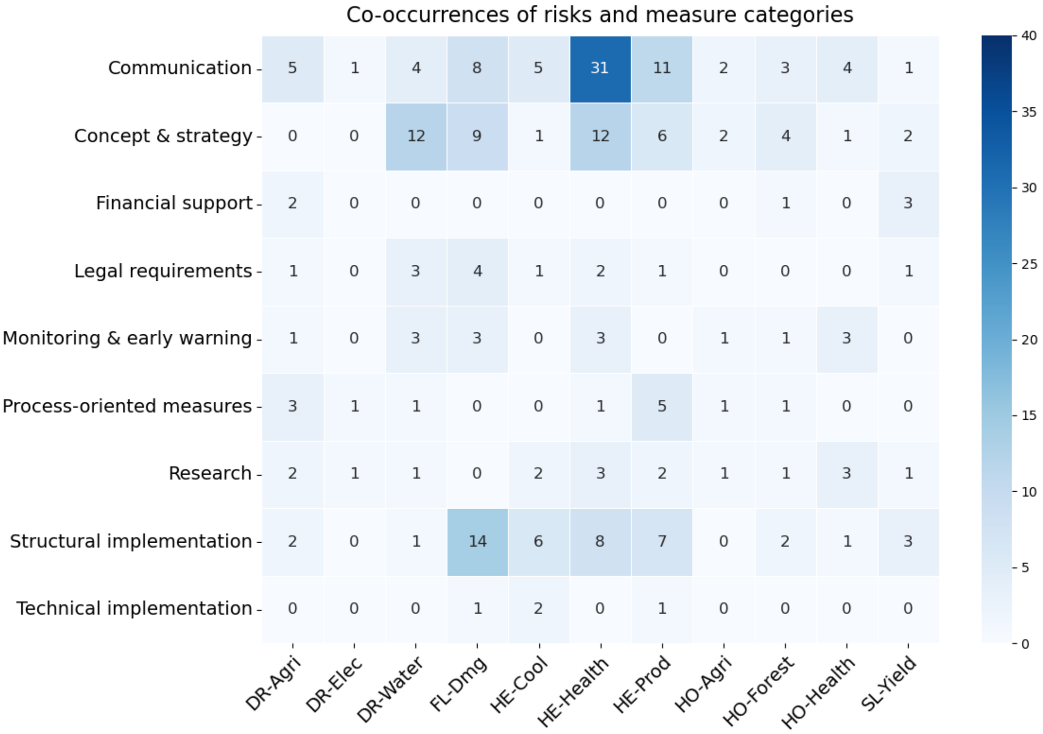
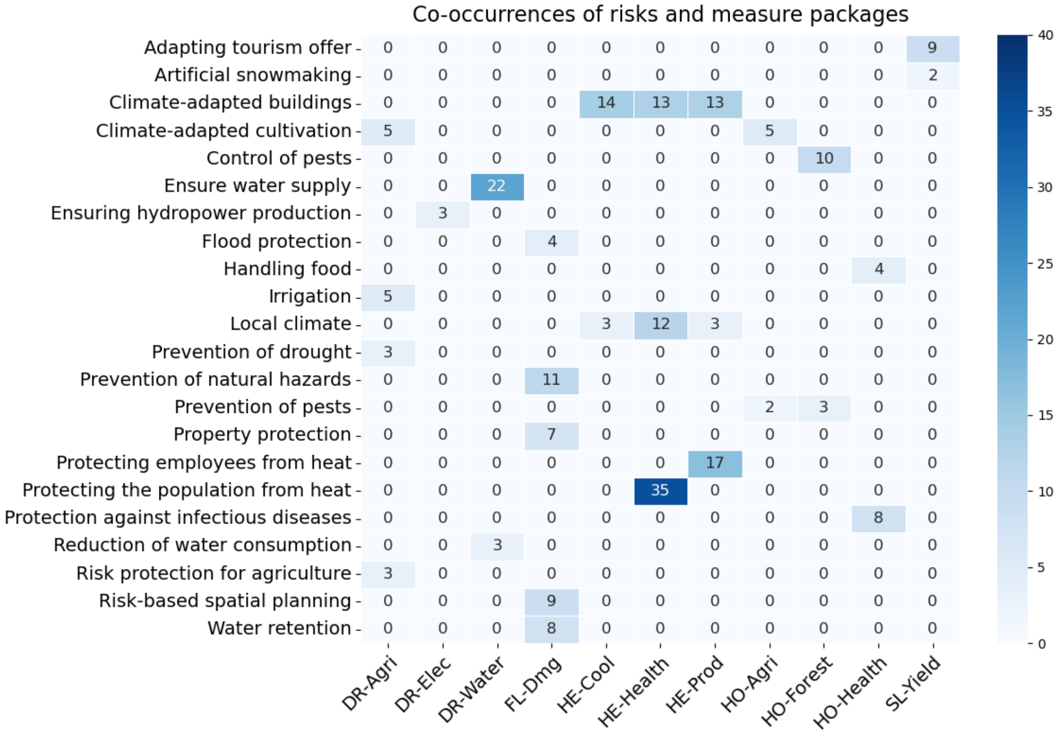


Figure 5.6: Co-occurrences of measure by the RiskID and Measure category. The co-occurrences show the number of measures in each combination.

The measure category categorizes the adaptation options into fields of action. The heat map represents the frequency with which different measure categories address the climate risks. With 75 of the measures, "Communication" is the most common form of adaptation, and is highly utilized in addressing "Rising heat stress levels" (HE-Health, 31 measures). With 11 measures, "Loss of productivity at work" (HE-Prod) is a prominent target as well. "Concept and strategy" measures are prominent in addressing "Water scarcity" (DR-Water) and HE-Health with 12 measures each. "Structural implementations" most often addresses the FL-Dmg to reduce flood damages. The risks of greater heat stress are addressed by various structural implementations with a total of 21 measures, 6 for "Cooling energy demand" (HE-Cool), 8 for "Impairment of human health" (HE-Health), and 7 for "Loss of productivity at work" (HE-Prod). Measures for "Monitoring and early warning" are present in most of the risks as are "Research" focused measures. Only few risks are addressed by "Financial support" or through "Process-oriented measures". "Loss of income from winter tourism" (SL-Yield) is the risk receiving the most "Financial support" measures. A couple of measures induce changes in the "Legal requirements" to address certain risks. Only 4 measures are about "Technical implementations".

Figure 5.7 shows that the measure packages are not independent from the climate risks which they address. Most of the packages only target on risk. An exception is the "Climate-adapted buildings" which addresses 3 risks. There are 14 measures for "Cooling energy demand" (HE-Cool), 13 for "Impairment of human health due to heat stress" (HE-Health), and also 13 for "Loss of productivity at work" (HE-Prod). "Protecting the population form heat" is the single most mentioned measure package. With 22 measures, "Ensure water supply" is the second largest package of measures which highlights the importance of maintaining water availability in the face of droughts. "Protecting employees from heat" has 17 measures, emphasizing the importance of workplace safety in extreme heat.



	DR-Agri	DR-Elec	DR-Water	FL-Dmg	HE-Cool	HE-Health	HE-Prod	HO-Agri	HO-Forest	HO-Health	SL-Yield
Adapting tourism offer	0	0	0	0	0	0	0	0	0	0	9
Artificial snowmaking	0	0	0	0	0	0	0	0	0	0	2
Climate-adapted buildings	0	0	0	0	14	13	13	0	0	0	0
Climate-adapted cultivation	5	0	0	0	0	0	0	5	0	0	0
Control of pests	0	0	0	0	0	0	0	0	10	0	0
Ensure water supply	0	0	22	0	0	0	0	0	0	0	0
Ensuring hydropower production	0	3	0	0	0	0	0	0	0	0	0
Flood protection	0	0	0	4	0	0	0	0	0	0	0
Handling food	0	0	0	0	0	0	0	0	0	4	0
Irrigation	5	0	0	0	0	0	0	0	0	0	0
Local climate	0	0	0	0	3	12	3	0	0	0	0
Prevention of drought	3	0	0	0	0	0	0	0	0	0	0
Prevention of natural hazards	0	0	0	11	0	0	0	0	0	0	0
Prevention of pests	0	0	0	0	0	0	0	2	3	0	0
Property protection	0	0	0	7	0	0	0	0	0	0	0
Protecting employees from heat	0	0	0	0	0	0	17	0	0	0	0
Protecting the population from heat	0	0	0	0	0	35	0	0	0	0	0
Protection against infectious diseases	0	0	0	0	0	0	0	0	0	8	0
Reduction of water consumption	0	0	3	0	0	0	0	0	0	0	0
Risk protection for agriculture	3	0	0	0	0	0	0	0	0	0	0
Risk-based spatial planning	0	0	0	9	0	0	0	0	0	0	0
Water retention	0	0	0	8	0	0	0	0	0	0	0

Figure 5.7: Co-occurrences of measure by the RiskID and Measure package. The co-occurrences show the number of measures in each combination.

Figure A.3 shows the co-occurrence of the actors and measure category. It highlights the importance of the federal authorities for implementing climate adaptation measures. Further, the figure indicates that most of the measures are based on "Communication" and "Concepts and strategies" performed by the Federal Government and the Cantons.

5.1.2 Associations

The following heat maps consist of the Chi-square statistics showing the relevance of the relationship between the different groups. The Chi-square statistics quantifies how much the observed counts in each combination deviate from the expected counts if there was no association. High values indicate a stronger deviation from the null hypothesis of independence, suggesting a significant association. The numbers within each cell corresponds to the Chi-square statistics between the corresponding combination.

The Chi-square statistics between the "RiskID" and "Actors" is shown in Figure 5.9. With a Chi-square value of 10.5, "Corporations" show a significant relevance for "Loss of income from winter tourism" (SL-Yield). An active involvement of academic institutes in addressing the "Impairments of forest services" (HO-Forest) is suggested with a score of 5.0. The combinations mentioned before are the only two which show a statistical significance with a p-value ≤ 0.5 (Figure A.4). However, the values of the Chi-square statistics are quite small compared with the other figures.

The heat map in Figure 5.9 illustrates the Chi-square statistics for the relevance of the relationships between the risks and target audiences. "Corporations" have a very high relevance with "Harvest losses in agriculture" (DR-Agri) with a value of 52.3. Most of the associations between the various risks and "Corporations" show a significant interaction (p-value ≤ 0.5, Figure A.5). The Chi-square value of 39.7 indicates a high relevance of the target audience "Part of the population" with the risk "Loss of productivity at work" (HE-Prod). The entire population has a high association with "Increasing risk of flooding" (FL-Dmg), indicating that personal and property damage affects the general public. "Vulnerable groups" only show a significant association with the risk "Impairment of human health from greater heat stress" (HE-Health).

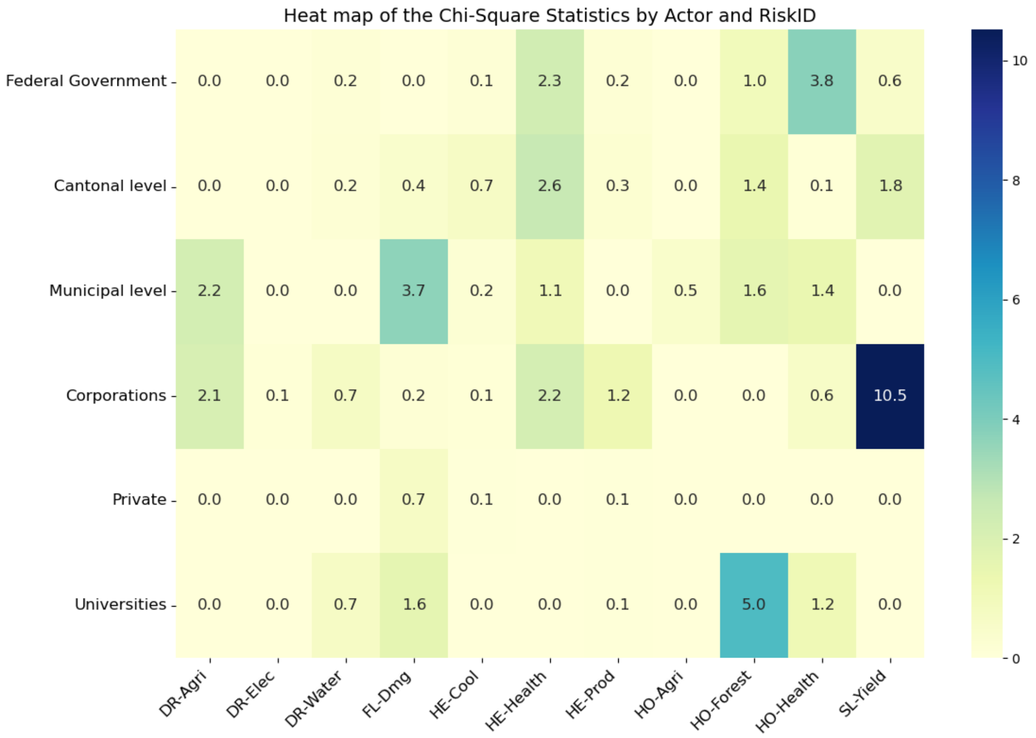


Figure 5.8: Chi-square statistic of correlation for the RiskIDs and Actors.

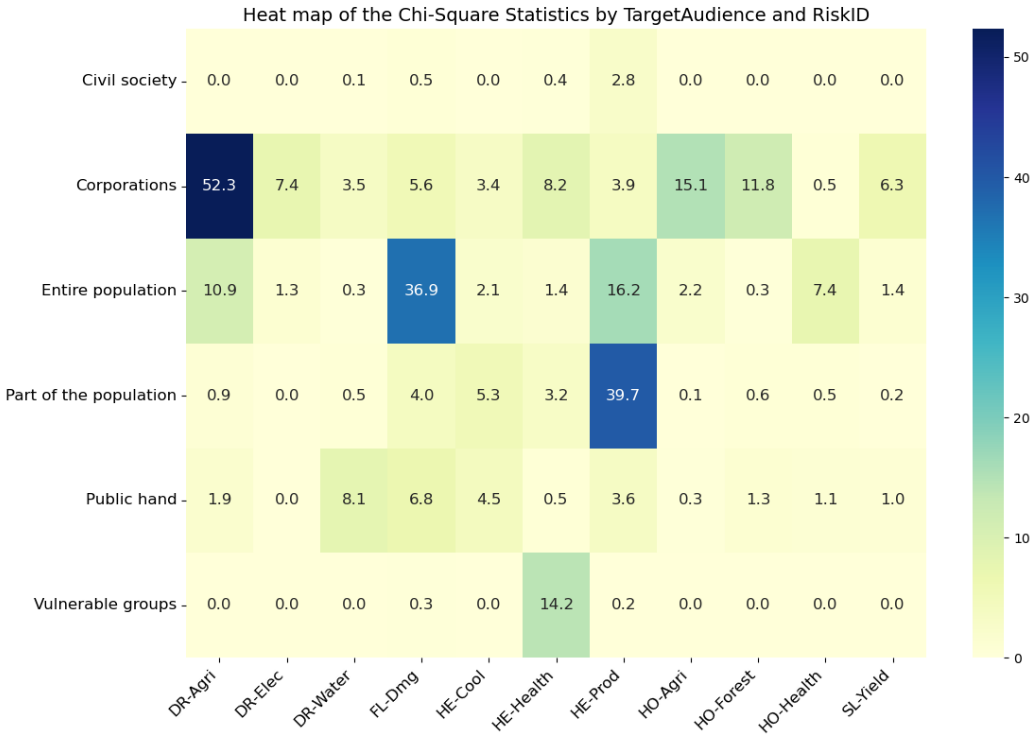


Figure 5.9: Chi-square statistic of correlation for the RiskIDs and Target audiences.

In the heat map for the associations between the "RiskID" and the "Measure category" (Figure 5.10), the highest relevance occurs between "Financial support" and "Loss of income from winter tourism" (SL-Yield). This indicates that funds are crucial to reduce losses in winter tourism. "Communication" is highly associated with greater heat stress and its effects on human health (HE-Health), showing the importance of sensitisation to manage health risks associated with heat. With a Chi-square value of 10.8, "Concept and strategy" shows a high relevance in addressing "Water scarcity" (DR-Water). "Structural implementations" show a high association with "Increasing risk of flooding" (FL-Dmg), suggesting high relevance of infrastructure adaptations to mitigate flood risk. There is no combination between the risks and "Legal requirements" or "Research" for which a high relevance is indicated. The Chi-square value of 3.5 for "Research" and the "Impairments of human health through harmful organisms" (HO-Health) is not significant (p-value > 0.5, see Figure A.6).

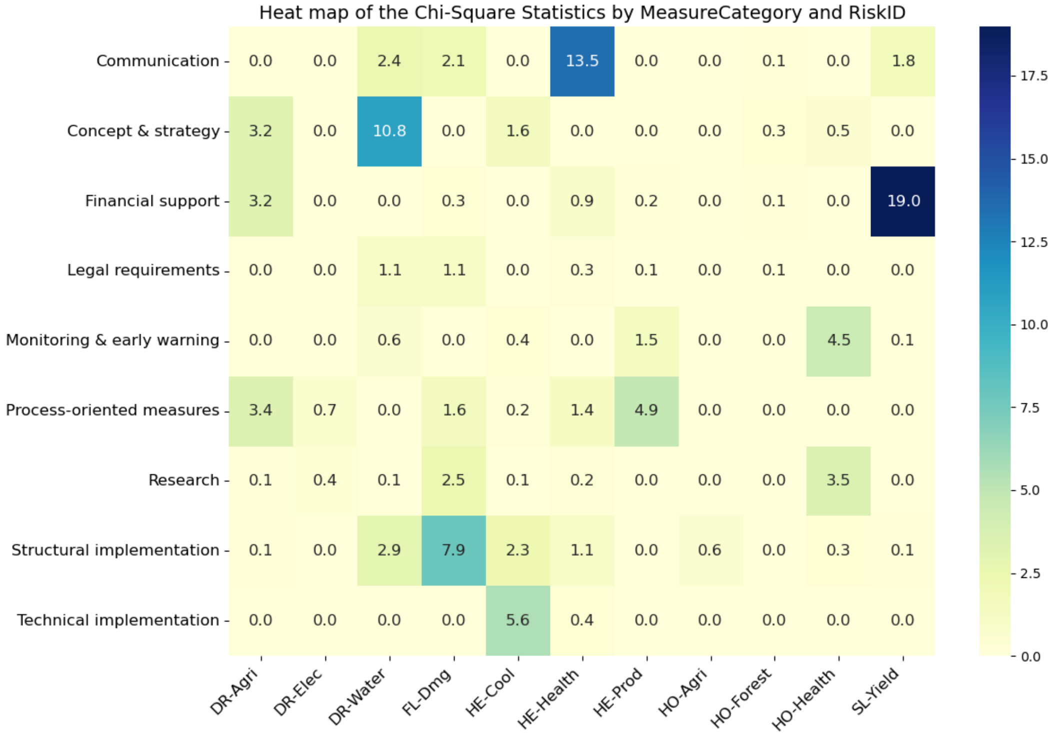
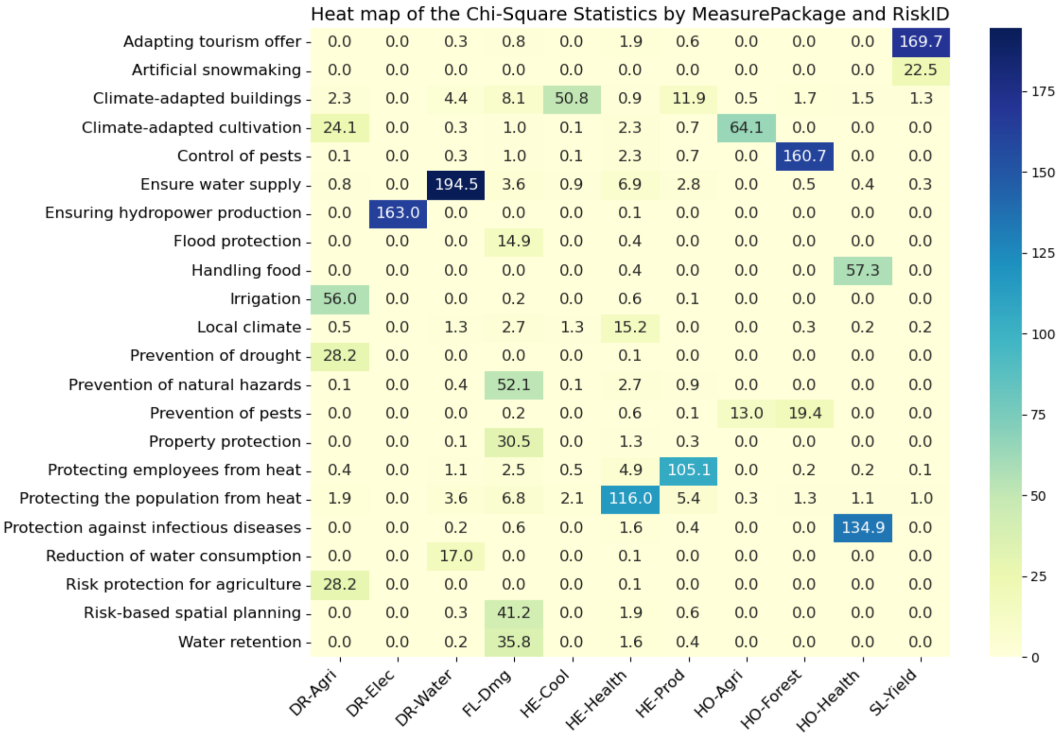


Figure 5.10: Chi-square statistic of correlation for the RiskIDs and Measure categories.

Figure 5.11 shows the relevance of the relationships between the "RiskID" and "Measure packages". The picture is quite similar to the co-occurrences in Figure 5.5 with a clear relation between one measure package and one risk each. Other interactions are close to zero, suggesting no association. Only two risks, "Harvest losses in agriculture" (DR-Agri) and "Increasing risk of flooding" (FL-Dmg), have multiple packages with a relevant association. Figure A.7 shows the significant associations where larger number remain.



	DR-Agri	DR-Elec	DR-Water	FL-Dmg	HE-Cool	HE-Health	HE-Prod	HO-Agri	HO-Forest	HO-Health	SL-Yield
Adapting tourism offer	0.0	0.0	0.3	0.8	0.0	1.9	0.6	0.0	0.0	0.0	169.7
Artificial snowmaking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5
Climate-adapted buildings	2.3	0.0	4.4	8.1	50.8	0.9	11.9	0.5	1.7	1.5	1.3
Climate-adapted cultivation	24.1	0.0	0.3	1.0	0.1	2.3	0.7	64.1	0.0	0.0	0.0
Control of pests	0.1	0.0	0.3	1.0	0.1	2.3	0.7	0.0	160.7	0.0	0.0
Ensure water supply	0.8	0.0	194.5	3.6	0.9	6.9	2.8	0.0	0.5	0.4	0.3
Ensuring hydropower production	0.0	163.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Flood protection	0.0	0.0	0.0	14.9	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Handling food	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	57.3	0.0
Irrigation	56.0	0.0	0.0	0.2	0.0	0.6	0.1	0.0	0.0	0.0	0.0
Local climate	0.5	0.0	1.3	2.7	1.3	15.2	0.0	0.0	0.3	0.2	0.2
Prevention of drought	28.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Prevention of natural hazards	0.1	0.0	0.4	52.1	0.1	2.7	0.9	0.0	0.0	0.0	0.0
Prevention of pests	0.0	0.0	0.0	0.2	0.0	0.6	0.1	13.0	19.4	0.0	0.0
Property protection	0.0	0.0	0.1	30.5	0.0	1.3	0.3	0.0	0.0	0.0	0.0
Protecting employees from heat	0.4	0.0	1.1	2.5	0.5	4.9	105.1	0.0	0.2	0.2	0.1
Protecting the population from heat	1.9	0.0	3.6	6.8	2.1	116.0	5.4	0.3	1.3	1.1	1.0
Protection against infectious diseases	0.0	0.0	0.2	0.6	0.0	1.6	0.4	0.0	0.0	134.9	0.0
Reduction of water consumption	0.0	0.0	17.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Risk protection for agriculture	28.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Risk-based spatial planning	0.0	0.0	0.3	41.2	0.0	1.9	0.6	0.0	0.0	0.0	0.0
Water retention	0.0	0.0	0.2	35.8	0.0	1.6	0.4	0.0	0.0	0.0	0.0

Figure 5.11: Chi-square statistic of correlation for the RiskIDs and Measure packages.

5.2 Assessment of the Feasibility and Effectiveness

For the feasibility and effectiveness, the qualitative scores of low, medium, and high, determined through the expert assessment, were transferred to quantitative scores of 1 (=low), 2 (=medium), and 3 (=high). To assess the overall feasibility or effectiveness, the mean was calculated and illustrated together with the SD for the Actors, Target audiences, Measure packages, and Measure categories. Using the mean to display the feasibility and effectiveness is in line with the practice used in the IPCC AR6 Europe chapter (Bednar-Friedl et al. 2022). Further, the number of adaptation measures in low, medium, and high in each proxy were counted.

5.2.1 Feasibility Assessment

The following figures show the mean and SD calculated with the sustainability, financial affordability, co-benefits, flexibility, and maladaptation. 3 is the highest possible score and 1 is the lowest score.

With the exception of SL-Yield (Loss of income from winter tourism), the feasibility in Figure 5.12 is perceived as high. With a mean feasibility score of 3.0, measures for managing the risks from "Harmful organisms, diseases, and invasive species" in both forests services (HO-Forest) and impairments of human health (HO-Health) achieve the highest score. The standard deviation for "Cooling energy demand" (HE-Cool) is quite extensive, suggesting strongly varying feasibility scores for the different proxies.

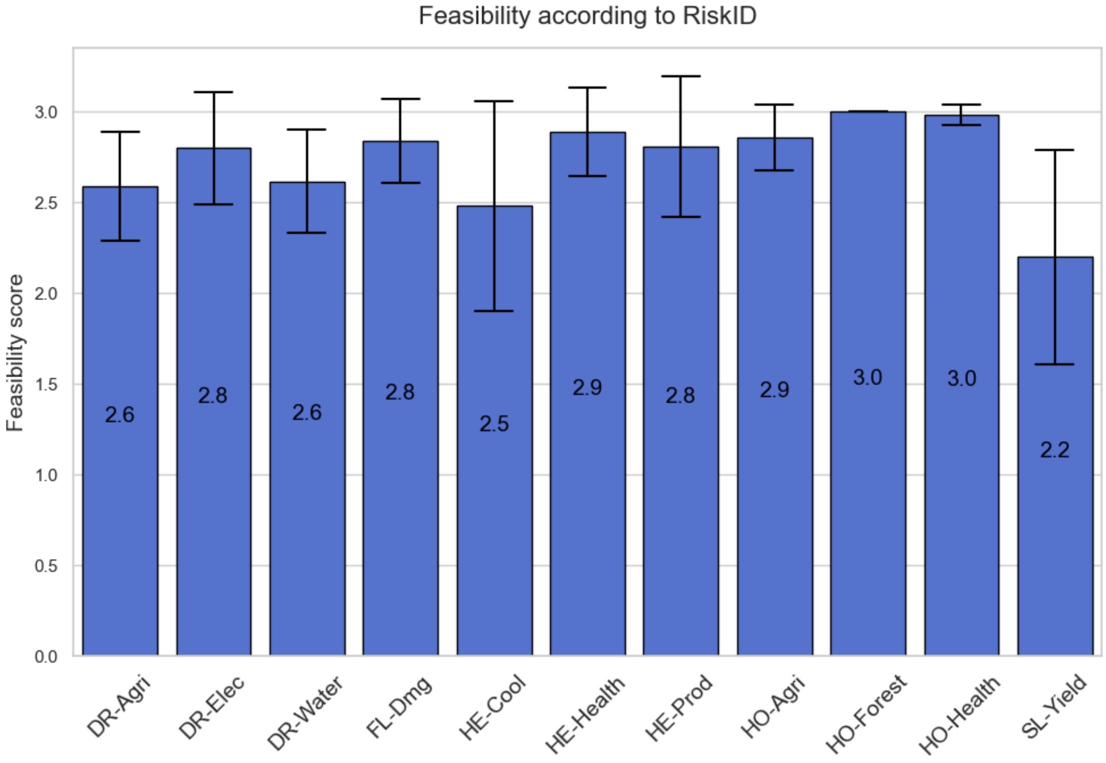


Figure 5.12: Mean and SD for the feasibility grouped by the RiskID.

Figure 5.13 shows that the overall feasibility is high for most actors. However, measures from "Corporations" and "Private" exhibit more moderate feasibility, with mean scores of 2.5 and 2.4, respectively. Additionally, the SD is larger for these two groups.

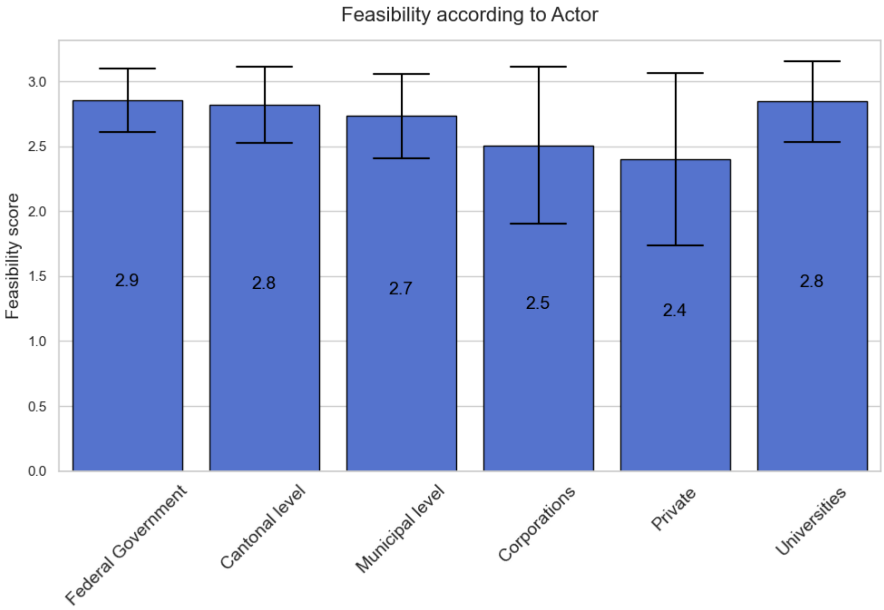


Figure 5.13: Mean and SD for the feasibility grouped by the actors.

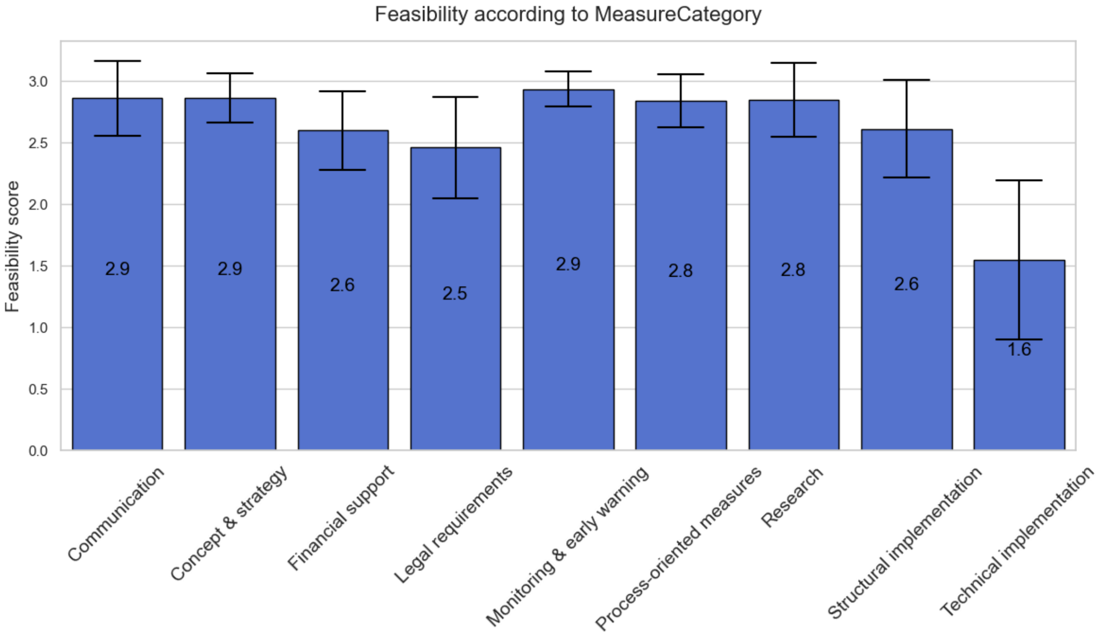


Figure 5.14: Mean and SD for the feasibility grouped by the measure categories.

Figure 5.14 shows the mean and SD for the measure categories. Most of the categories are perceived as highly feasible with scores of 2.8 and 2.9. With a score of 2.6, "Financial support" and "Structural implementation" are relatively less feasible. The exception is "Technical implementation" with a score of 1.6.

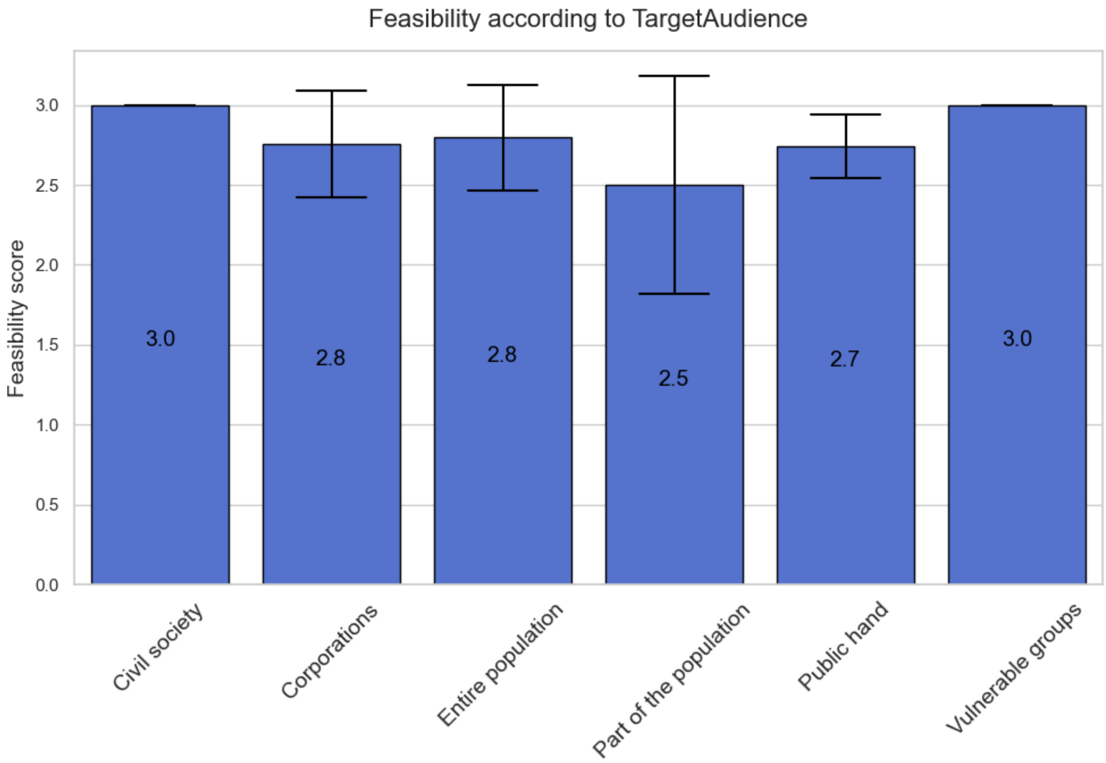


Figure 5.15: Mean and SD for the feasibility grouped by the target audiences.

Most of the measures grouped by the target audience are perceived as highly feasible with scores of 2.7 to 3.0 (Figure 5.15). Only measures addressed to "Part of the population" have a relatively lower feasibility with 2.5.

The feasibility grouped by the measure packages in Figure 5.16 reveals that multiple packages get a high score of 3.0, suggesting strong confidence in implementing these measures. "Climate-adapted buildings" (2.5) and "Climate-adapted cultivation" (2.6) show a medium to high overall feasibility, suggesting that certain proxies are less feasible. Measure packages in favor of reducing "Loss of income from winter tourism" have the lowest feasibility score with 2.3 for "Adapting tourism offer" and 1.7 for "Artificial snowmaking".

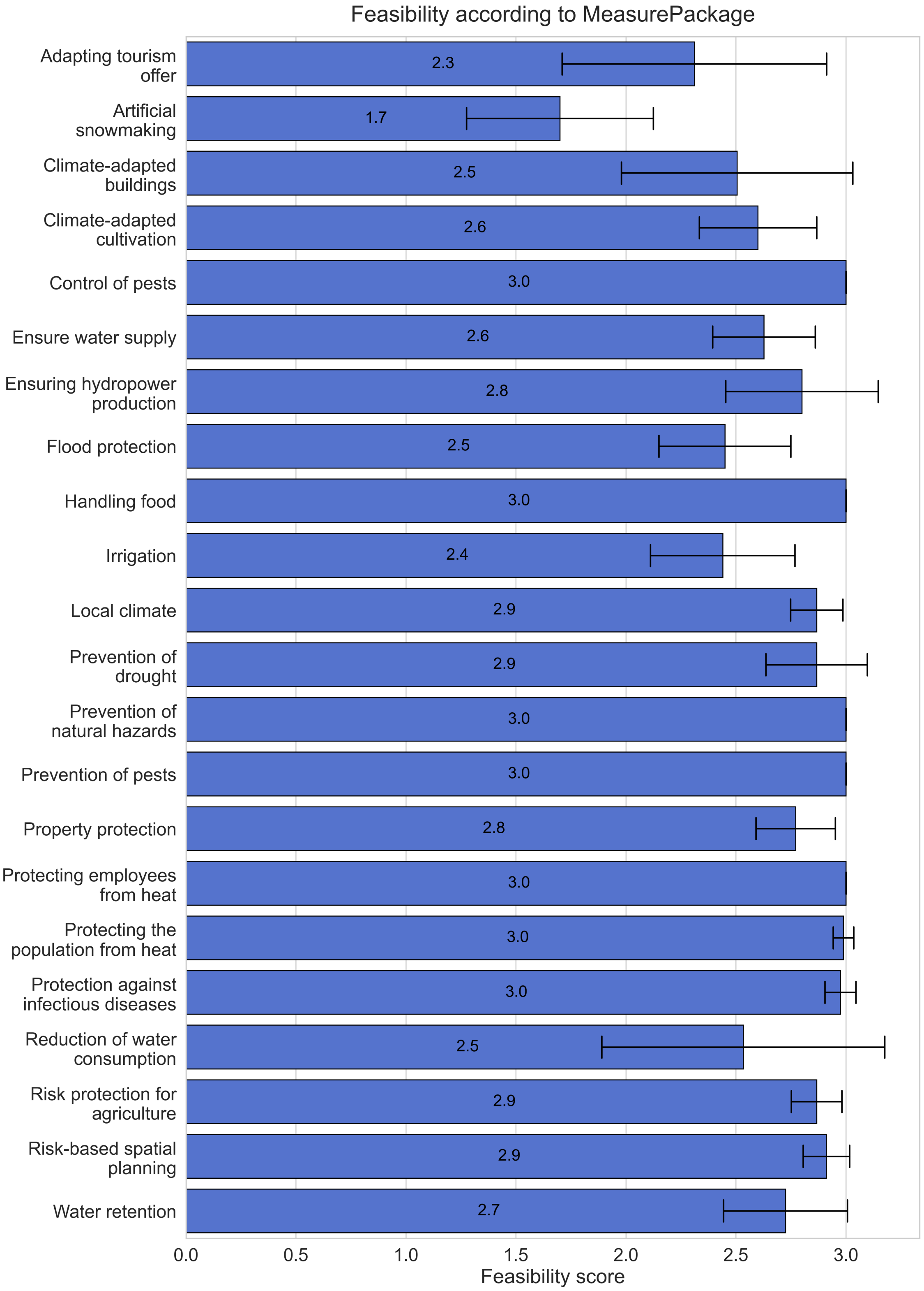


Figure 5.16: Mean and SD for the feasibility grouped by the measures packages.

Figure 5.17 shows number of measures for each score across the proxies used in the feasibility assessment. A large portion of the measures exhibit a high scoring in all categories. "Sustainability" represents the socio-political acceptability by ensuring that the measure takes the balance of the economy, ecology, and society into account. Only eight measures received a low score. "Avoiding maladaptation", which describes the socio-political dimension, seems to be of high importance since this score shows the largest amount of "high" scores. With only six measures scored at "low", the "Financial affordability" is given in most adaptation measures, suggesting that most measures can be implemented at a reasonable cost. Both, the "Flexibility" and the "Financial affordability" describe the economic dimension of the adaptation measures. The "Flexibility" has the highest number of low scores, indicating that those measures can only be modified with larger investments. As 181 measures have a high score for the "Co-benefits", three quarters of the measures do not only achieve their goal but have a positive influence on other environmental or societal aspects.

Figure 5.17: The number of adaptation measures for each of the categories used for the feasibility assessment is shown in this figure. The qualitative scores are low, medium, and high, representing the perceived feasibility.

5.2.2 Effectiveness Assessment

The following figures show the scores for the robustness and effectiveness. Both are means to describe the effectiveness of the adaptation measures in the database. The "Effectiveness" in the database can be understood as the degree to which adaptation measures achieve their intended objective, as it is defined in previous literature (e.g. IPCC 2023; Singh et al. 2020). Whereas the "Robustness" describes qualitatively if the measures has positive impacts on reducing the risk under different climate scenarios.

Figure 5.18 depicts the mean and SD for the "Robustness" and "Effectiveness". It is clearly visible that the "Effectiveness" is lower across all risks with a larger SD. The most extreme example is "Impairments of human health through harmful organisms" (HO-Health) where the "Robustness" is 3.0 and the "Effectiveness" 1.1, suggesting that the measures do not have a strong impacts, but can be adapted under different climate scenarios. The highest "Effectiveness" score is in addressing the rising snow line (SL-Yield), indicating that these measures have direct impacts on the income in regions with winter tourism.

Figure 5.19 shows that the "Robustness" is medium to high across all actors, with scores of 2.4 to 2.8, indicating effects for every climate scenario. However, the "Effectiveness" is only low to medium. Measures performed by Corporations" and "Private" have medium "Effectiveness", suggesting some effect by implementing the measure. The lowest "Effectiveness" is seen in measures from "Universities" (1.2).

Measuring targeting "Parts of the population" or the "Public hand" have the relatively highest "Effectiveness" with scores of 2.0 and 1.9, respectively (Figure 5.20). However, the SD is quite large, suggesting uncertainty in the effect. Further, the "Robustness" for measures addressed at parts of the population show the relatively lowest "Robustness" with a score of 2.2. The "Effectiveness" for all target audiences is low to medium.

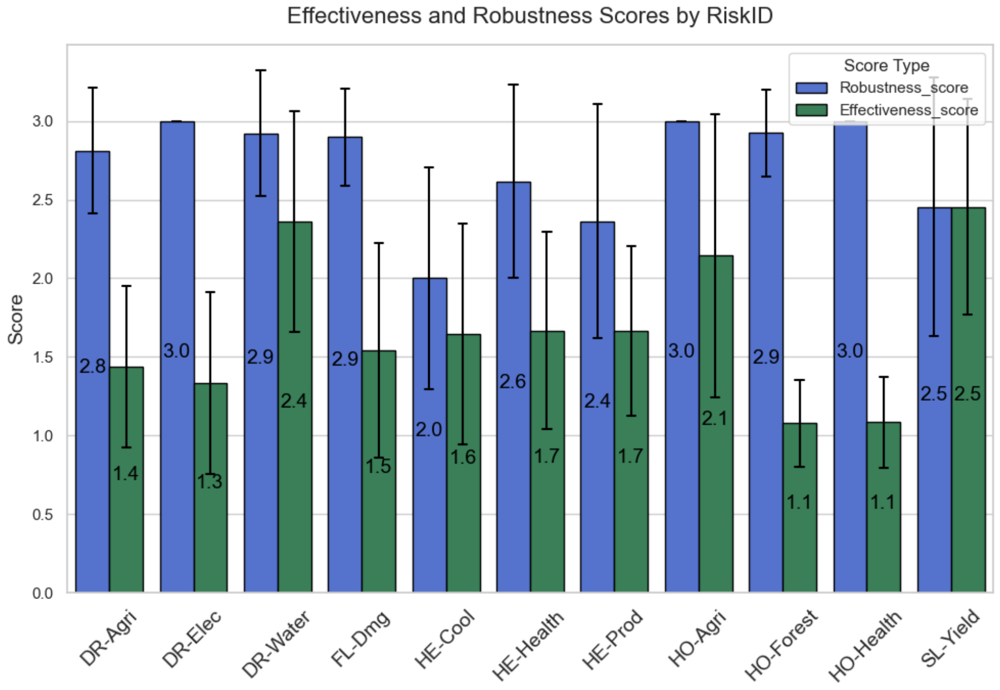


Figure 5.18: Mean and SD for the robustness and effectiveness grouped by the risks.

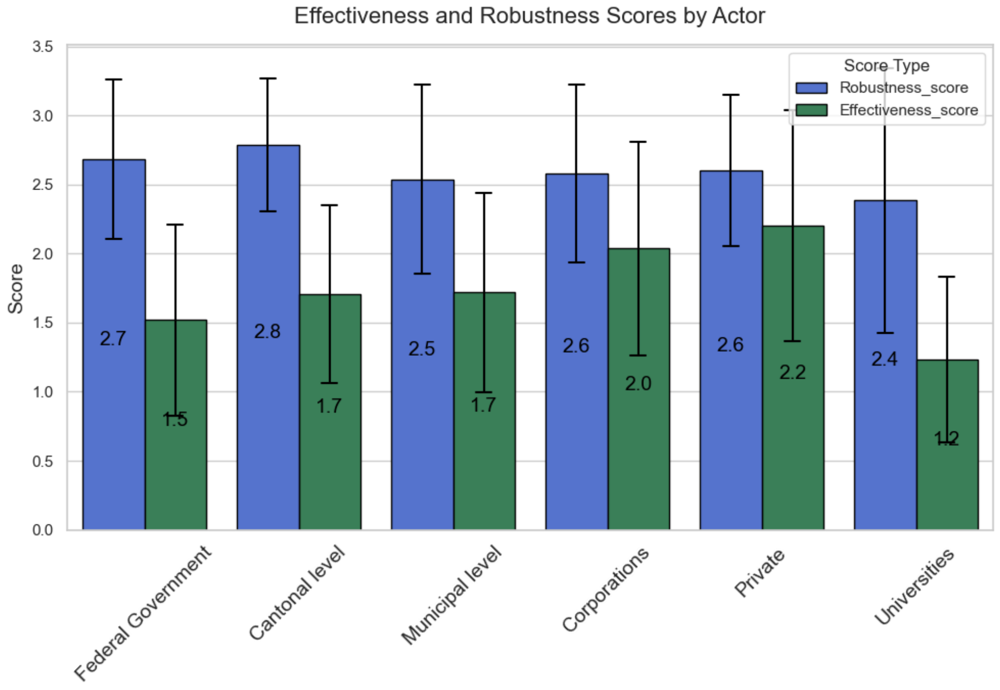


Figure 5.19: Mean and SD for the robustness and effectiveness grouped by the actors.

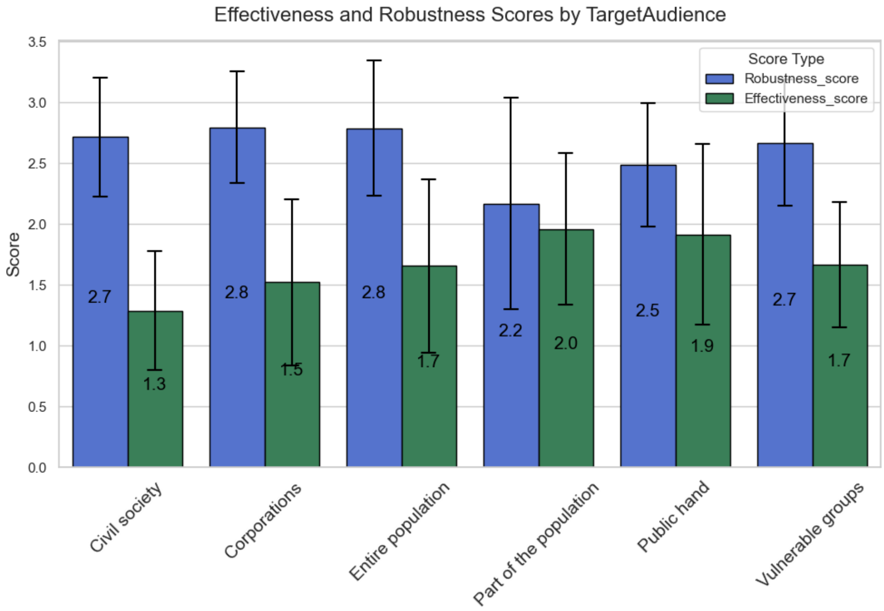


Figure 5.20: Mean and SD for the robustness and effectiveness grouped by the target audiences.

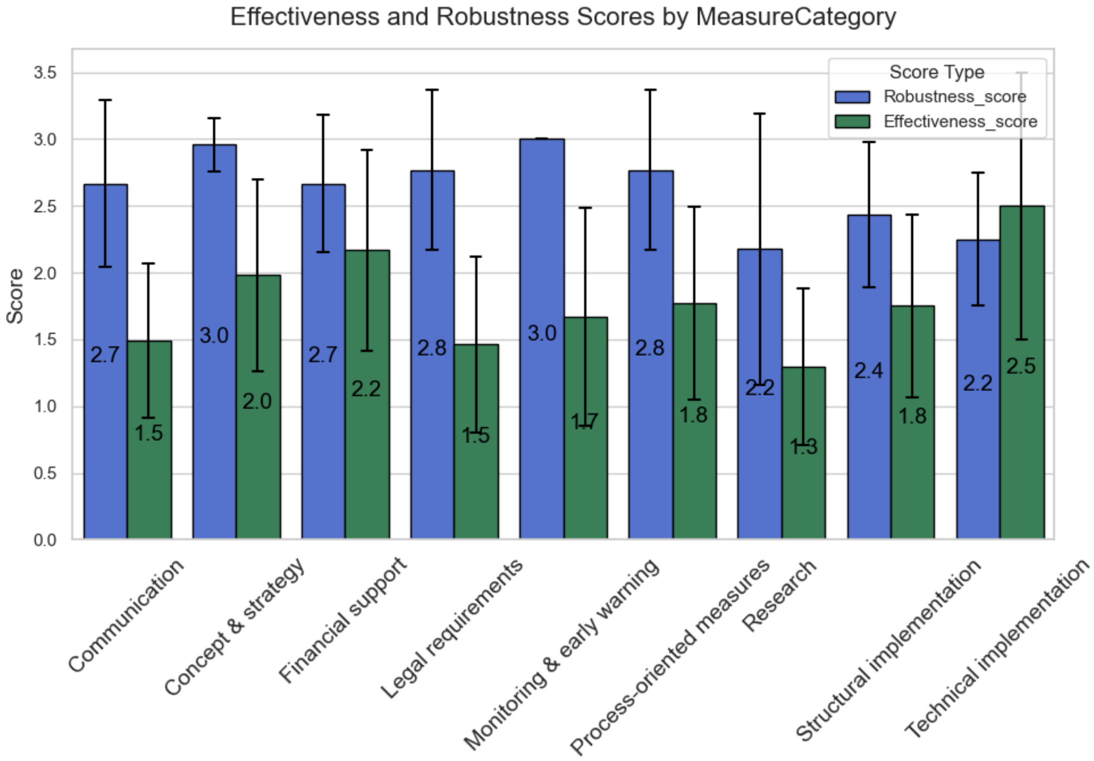


Figure 5.21: Mean and SD for the robustness and effectiveness grouped by the measure categories.

The "Effectiveness" grouped by the measure categories in Figure 5.21 range from 1.3 (Research) to 2.5 (Technical implementation). For the "Technical implementation", the "Robustness" has a lower score (2.2) than the "Effectiveness" (2.5). However, the SD for the "Effectiveness" is very large. "Monitoring and early warning", "Legal requirements", and "Communication" show a low to medium "Effectiveness", suggesting only small impacts in addressing the climate risks. "Research" (2.2), "Technical implementation" (2.2), and "Structural implementation" (2.4) have the relatively lowest "Robustness", indicating difficulties in adapting the measures to different climate scenarios.

Figure 5.23 shows the effectiveness and robustness scores for the measure packages. With an effectiveness of 2.7 and a robustness of 2.8, a strong impact on reducing the risks of a rising snow line is suggested for "Adapting tourism offer". In contrast, "Artificial snowmaking" has a low robustness (1.0), and a low to medium effectiveness (1.5). Many packages have high scores in robustness but show only minimal effectiveness (e.g. control of pests, handling food, prevention of drought, prevention of natural hazards). "Ensure water supply" and "Water retention" have medium to high scores for the effectiveness and high robustness, indicating strong impacts on combating water scarcity.

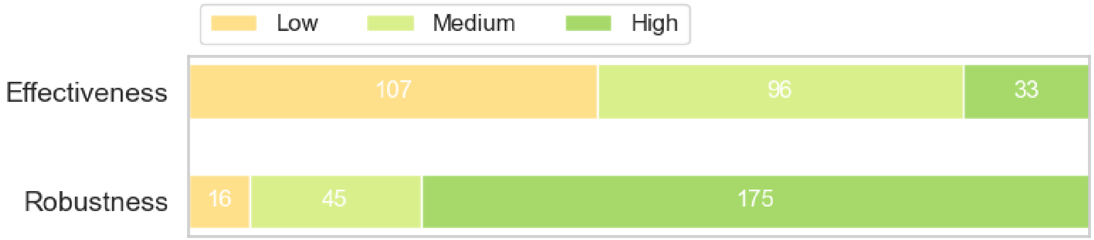


Figure 5.22: Number of adaptation measures in the scores for the effectiveness and robustness. The qualitative scores are low, medium, and high, representing the perceived effectiveness and robustness.

In Figure 5.22, it is clearly visible that only a few measures are perceived with a high effectiveness (33), while most measures have a low effectiveness (107). In contrast, the robustness is high for 175 solutions in the database, suggesting stable measures in regards to climate scenarios.

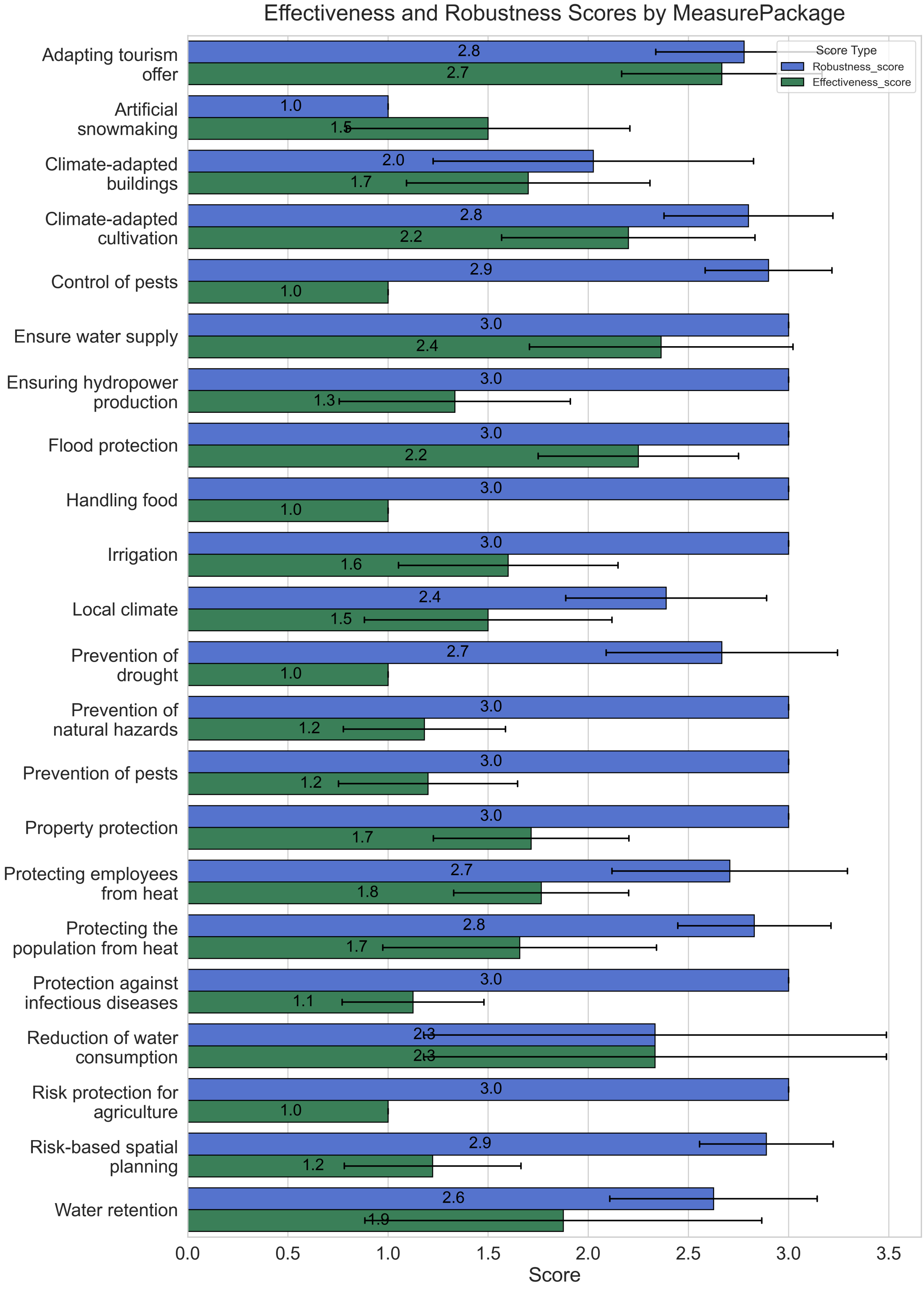


Figure 5.23: Mean and SD for the robustness and effectiveness grouped by the measure packages.

5.3 Database for the Cost Assessment

To do the cost assessment, the expert team assessed the quantifiability of the effect and the costs. For measures where quantifying is possible, implementation costs for the measures were looked for. In the end, 48 measures have been selected for which investment costs and/or annual costs were found. Investment costs are a one-time event to initialize the measure while annual costs occur yearly to keep the measure going or for maintenance of new systems.

In Figure 5.24, measure to reduce the effects of heat on human health (HE-Health) and the prevention of water scarcity (DR-Water) are most prominent, followed by HE-Prod. Not all risks are represented in the cost assessment since only for certain measures costs were available. The missing risks are DR-Elec, HO-Agri, and HO-Forest.

Most of the measures are to be financed by the "Cantonal level" (18), and the "Federal Government" (13). Only two measures were found to be financed by private households and the actor "Universities" is missing entirely.

In the measure categories (Figure 5.25), 14 costs for measures in the "Concept and Strategy" were found, followed by the "Structural implementation" with 12 measures and "Communication" with 10. For "Process-oriented measures" no costs were found.

Most costs were found in the measure packages "Ensure water supply" (13), and "Climate-adapted buildings" (10). This indicates a solid base for climate adaptation options in these packages. As there are multiple different ways to adapted buildings to the climate, for example with the "Installation of cooling systems" (e.g. reversible heat pump, split-air conditioning device) or the "Summer thermal protection", the figure is slightly skewed (see Table A.2). A number of measure packages are not present in the cost database as no costs were found for them: Risk-based spatial planning, Property protection, Water retention, Prevention of natural hazards, Artificial snowmaking, Handling food, Prevention of pests, Climate-adapted cultivation (for both DR-Agri and HO-Agri), Risk protection for agriculture, Ensuring hydropower production, and Reduction of water consumption.

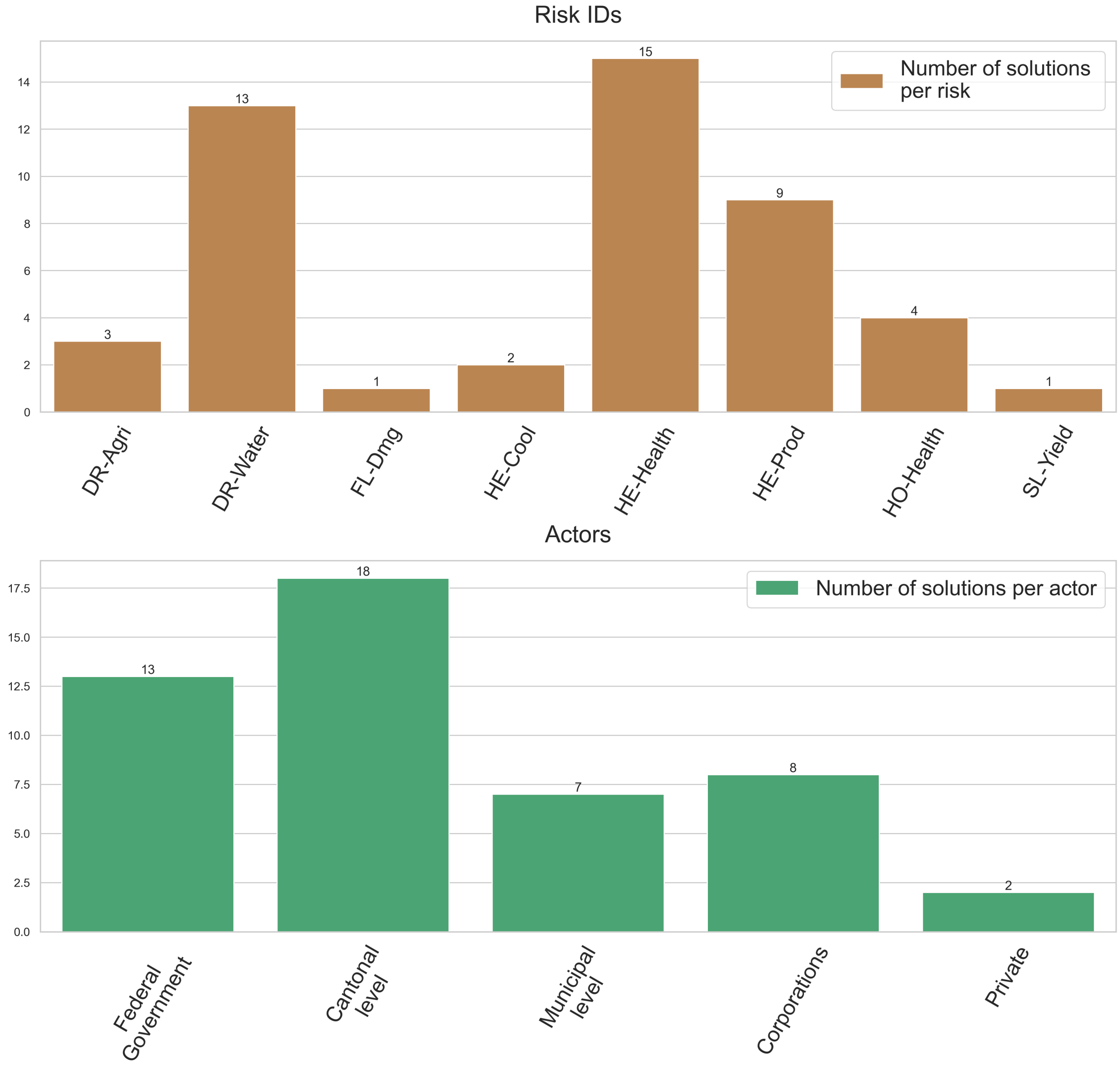


Figure 5.24: Number of solutions for the cost assessment for each risk and actor.

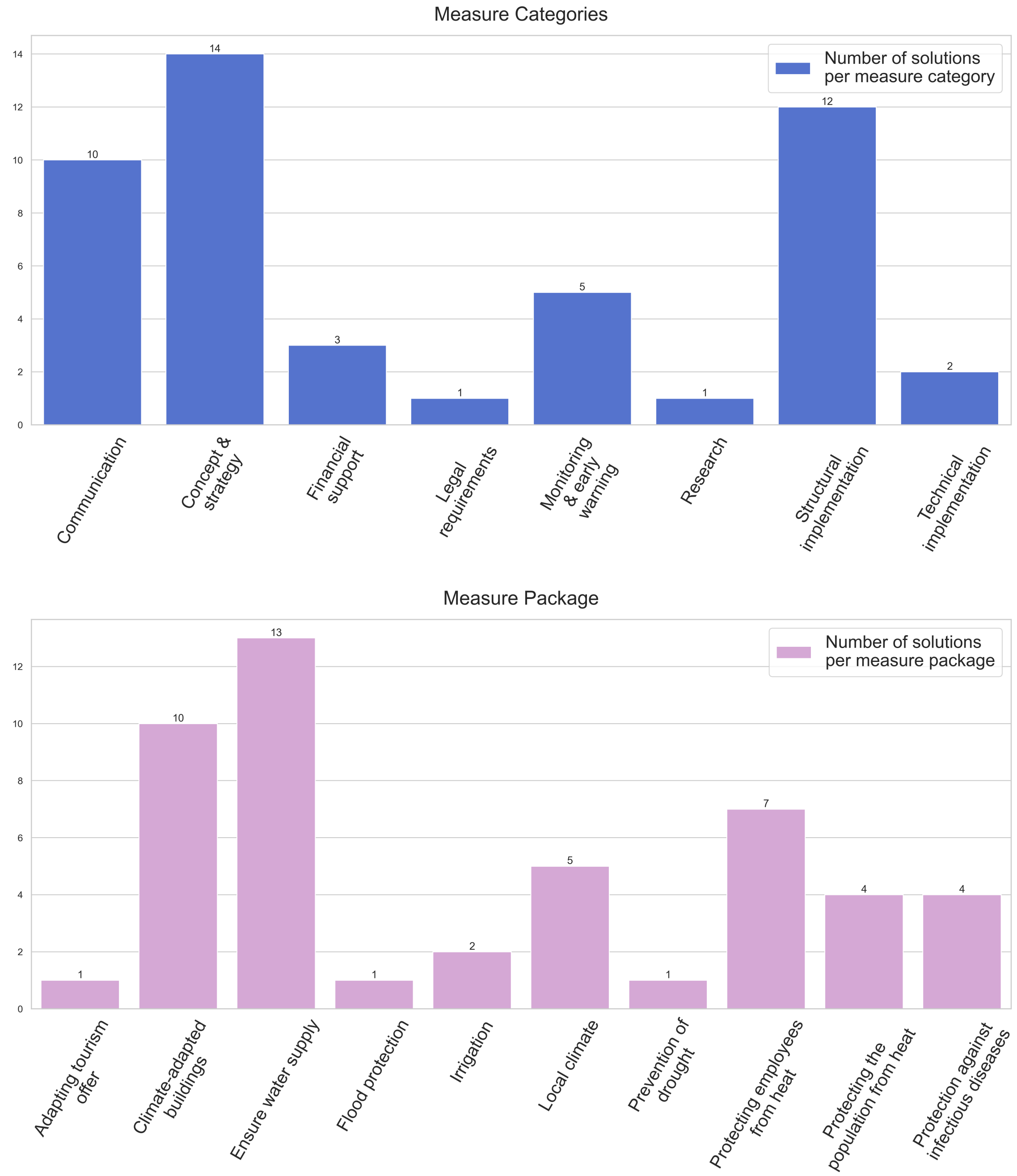


Figure 5.25: Number of solutions for the cost assessment for each measure category and measure package.

5.3.1 Cost Distribution

To assess the nationwide costs, the measure costs were first adjusted to the inflation level of 2023 and then extrapolated from the cantonal, building, or other levels to the national level. As mentioned in Section 4.4, three measures in the cost database were removed for the cost analysis. All figures in this section are without said measures. Figures including the three measures are in the appendix (Figures A.9, A.10, A.11, A.12, A.13, A.14, A.15, A.16).

Over the remaining 45 measures, the total cost for one-time investments (investment costs) are about CHF 9.3 billion. The annual costs are CHF 137.3 million per year. In Table A.3, the precise numbers are shown as well as the height of the investment and annual costs including the three removed measures.

Table 5.1: Total height of the annual and investment cost.

Without the 3 Measures	**Amount (CHF)**
Total Investment Costs	9’289’611’542
Total Annual Costs	137’322’111

Figures 5.26 and 5.27 show the investment and annual costs for the **RiskIDs**, respectively. The "Increasing risk of flooding" (Fl-Dmg) has by far the largest investment costs with CHF 7’815 million, followed by "Loss of productivity at work" (HE-Prod) with CHF 1’303 million. Other risks require considerably lower investments.
The annual costs show a different distribution. "Impairment of human health from greater heat stress" (HE-Health) incurs the highest annual cost with CHF 63.6 million, followed by "Cooling energy demand" (HE-Cool, CHF 24.2 million). The lower annual costs for "Harvest loss in agriculture due to drought" (DR-Agri) and HE-Prod suggests either less frequent maintenance or lower operational costs.

Analysing the investment costs across the different **Actors** reveals significant disparities (Figure 5.28). First of all, costs for "Universities" are missing entirely. The "Cantonal level" bears the highest burden with over CHF 7’945 million, followed by "Corporations" with CHF 1’305 million. In contrast, other actors have minimal to no costs.
Governmental authorities bear most of the annual costs with CHF 52.31 million at the "Cantonal level", CHF 43.45 million at the municipal, and CHF 39.69 million at the "Federal level" (Figure 5.29. "Corporations" and "Private" have low to no annual costs.

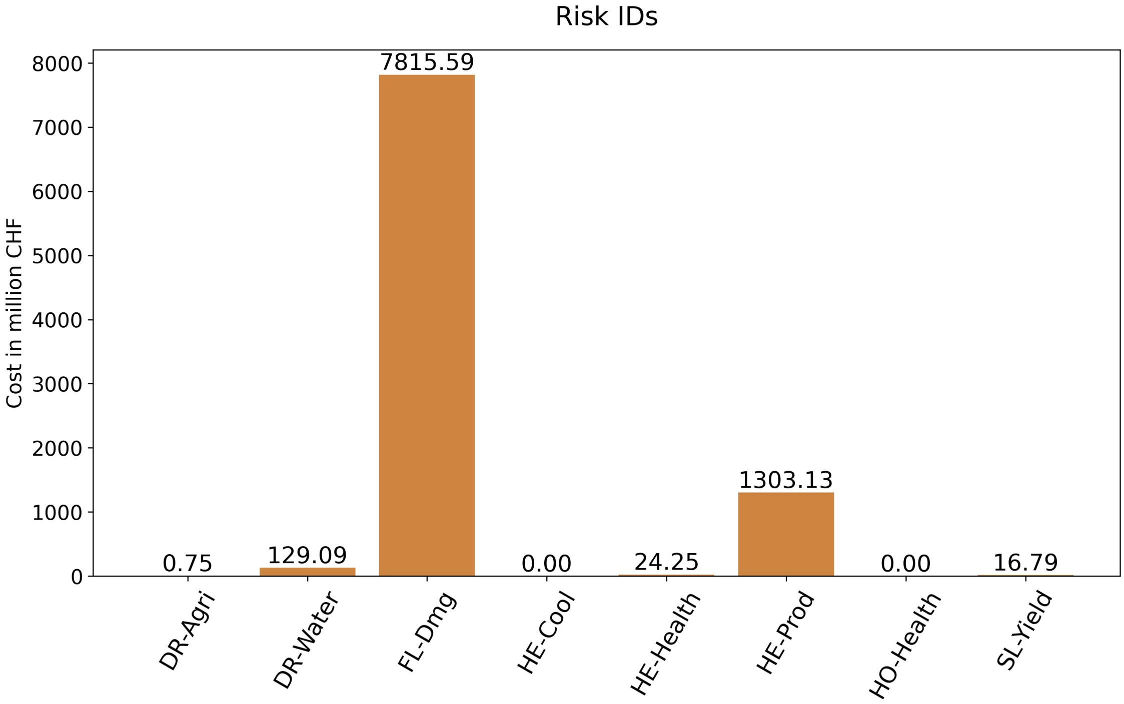


Figure 5.26: Investment Cost by RiskIDs without the three overlapping measures for cooling installations and summer thermal protection.

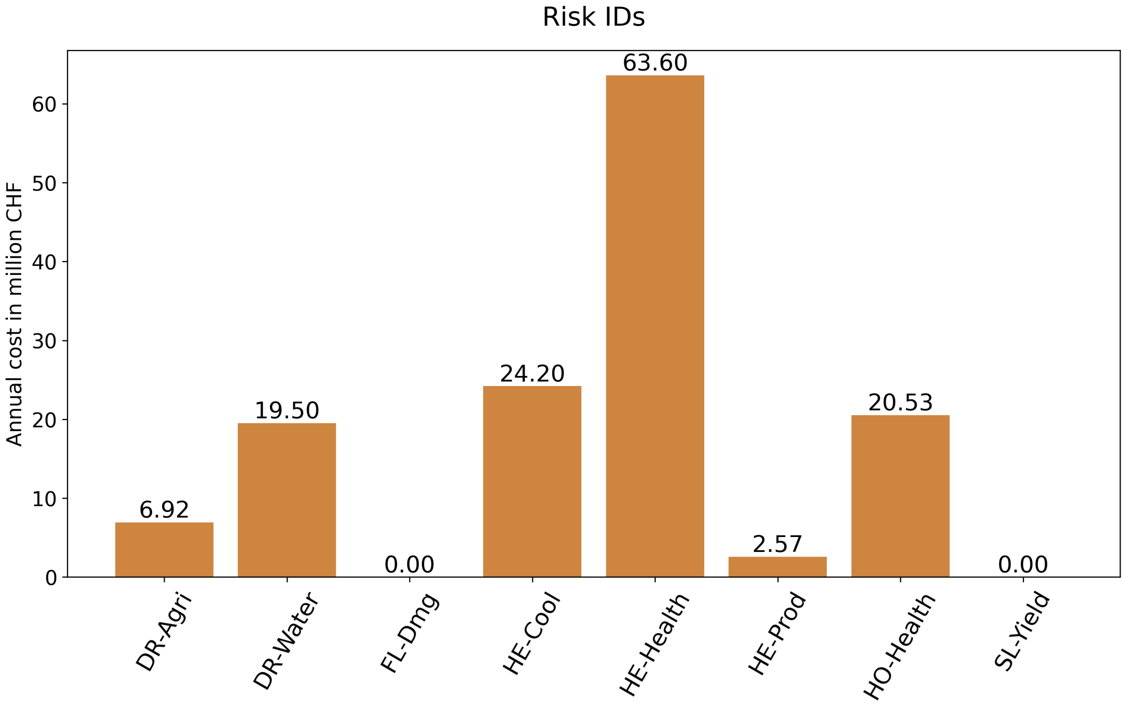


Figure 5.27: Annual Cost by RiskIDs without the three overlapping measures for cooling installations and summer thermal protection.

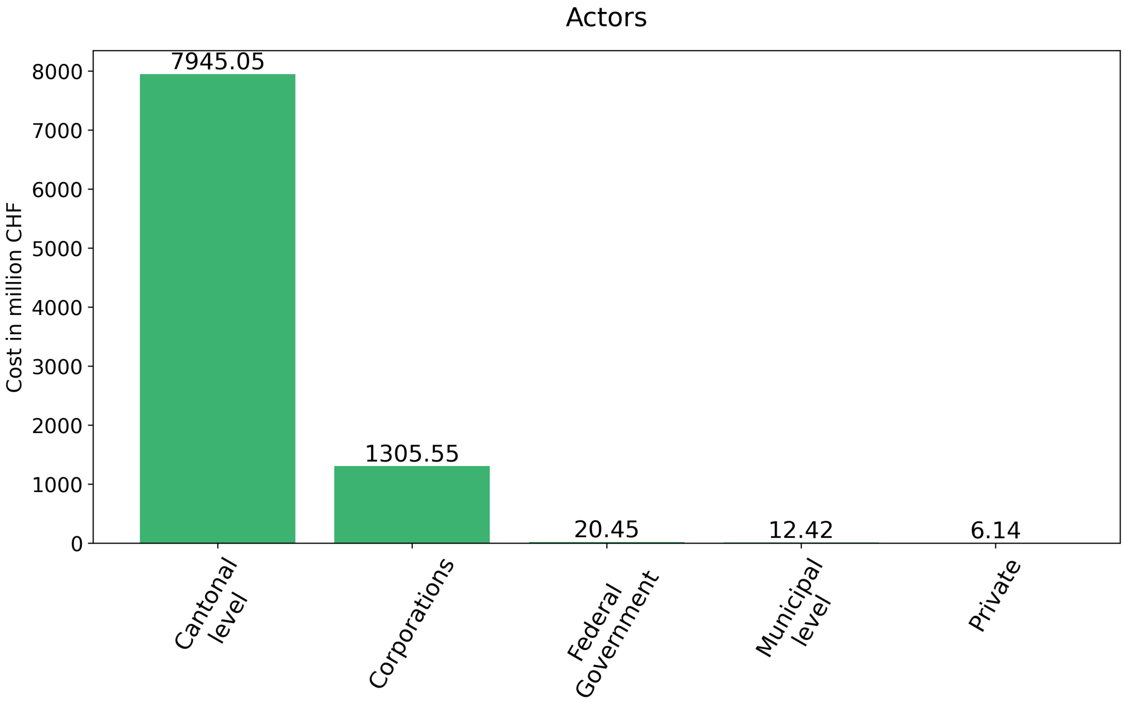


Figure 5.28: Investment Cost by Actors without the three overlapping measures for cooling installations and summer thermal protection.

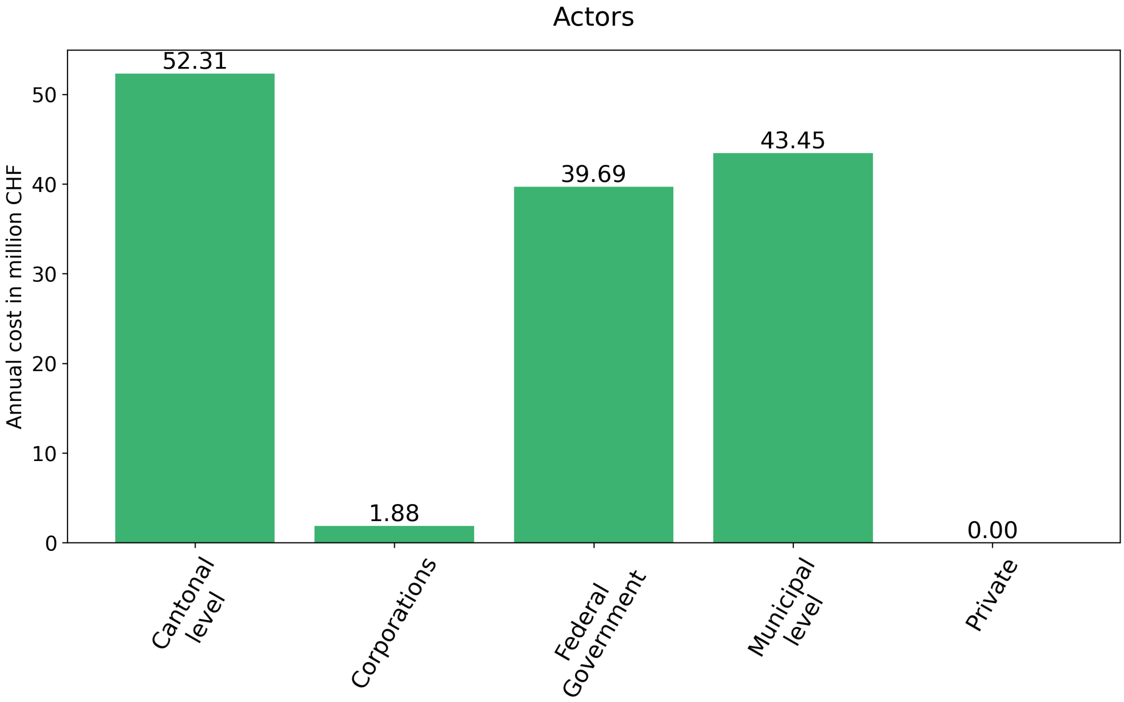


Figure 5.29: Annual Cost by Actors without the three overlapping measures for cooling installations and summer thermal protection.

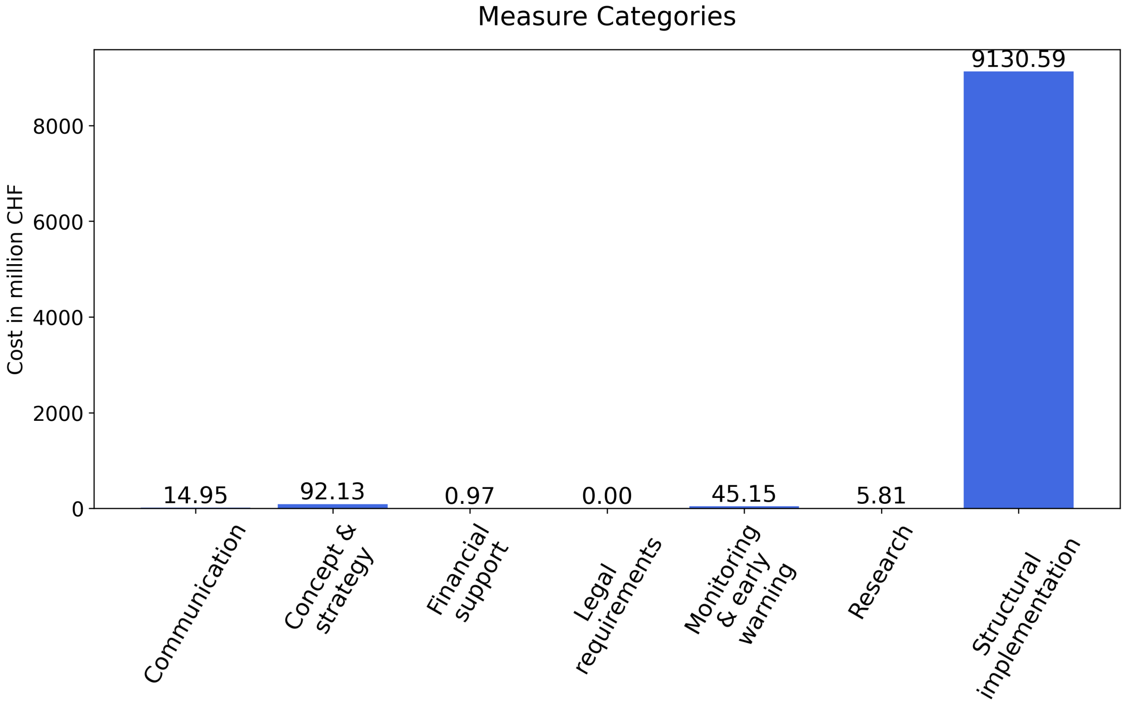


Figure 5.30: Investment Cost by Measure Categories without the three overlapping measures for cooling installations and summer thermal protection.

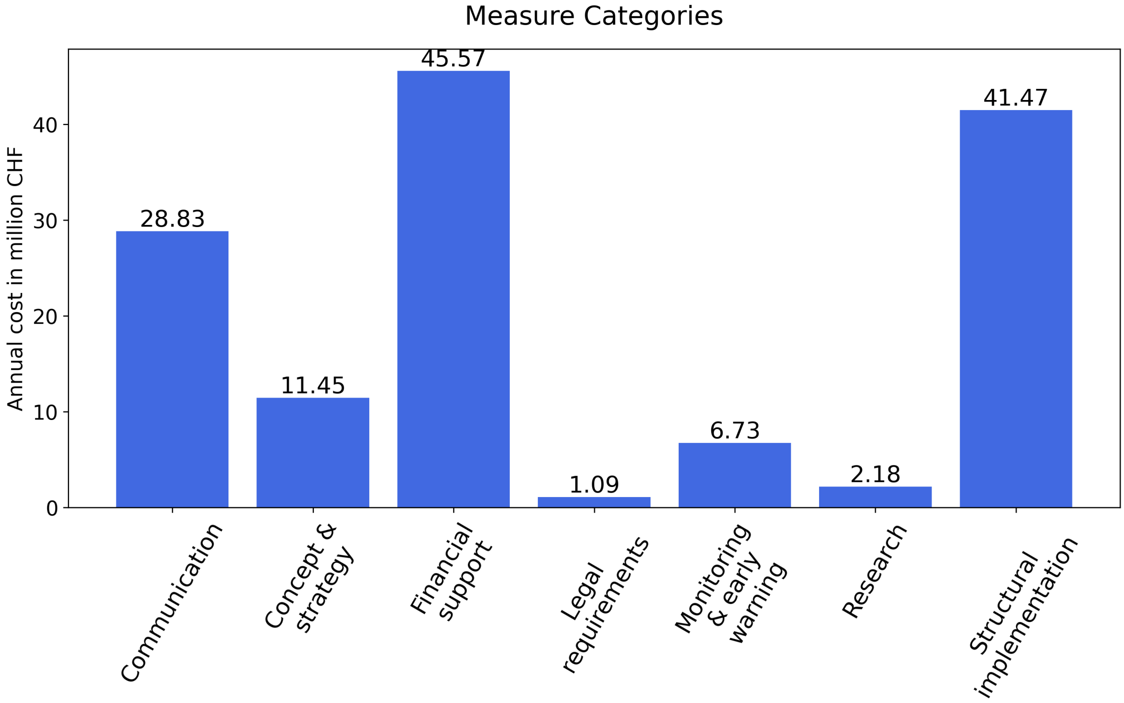


Figure 5.31: Annual Cost by Measure Categories without the three overlapping measures for cooling installations and summer thermal protection.

The analysis of investment costs across the **Measure categories** reveals a clear emphasis on expenditures related to "Structural implementations" with CHF 9'130 million (Figure 5.30). With CHF 92 million, "Concept and strategy" is the second highest cost factor. Other categories only show minimal or no investment costs.
For the annual costs, the picture is quite different (Figure 5.31). "Financial support" has the highest annual cost with CHF 45.57 million, reflecting ongoing subsidies. Interestingly, "Structural implementation" bears the second highest annual costs with CHF 41.47 million. With CHF 28.83 million, "Communication" also has notable ongoing costs, suggesting it to be a key component for the adaptation strategy. Other categories only show minimal annual costs.

The investment costs for the **Measure package** "Flood protection" in Figure 5.32 is CHF 7'815.59 million. Other significant investments include "Climate-adapted buildings" with CHF 1'294.37 million, followed by "Ensure water supply" with CHF 129.09 million. In contrast, other packages like "Adapting tourism offer", "Local climate" and "Irrigation" require significantly lower investments, indicating a focus on building resilience against floods and heat.
The annual costs (Figure 5.33) reveal that "Climate-adapted buildings" and "Local climate" incur the highest costs with CHF 45.82 million and CHF 41.16 million, respectively. With annual costs of CHF 20.53 million, the "Protection against infectious diseases" is the third largest annual expense, closely followed by "Ensure water supply" with CHF 19.50 million.

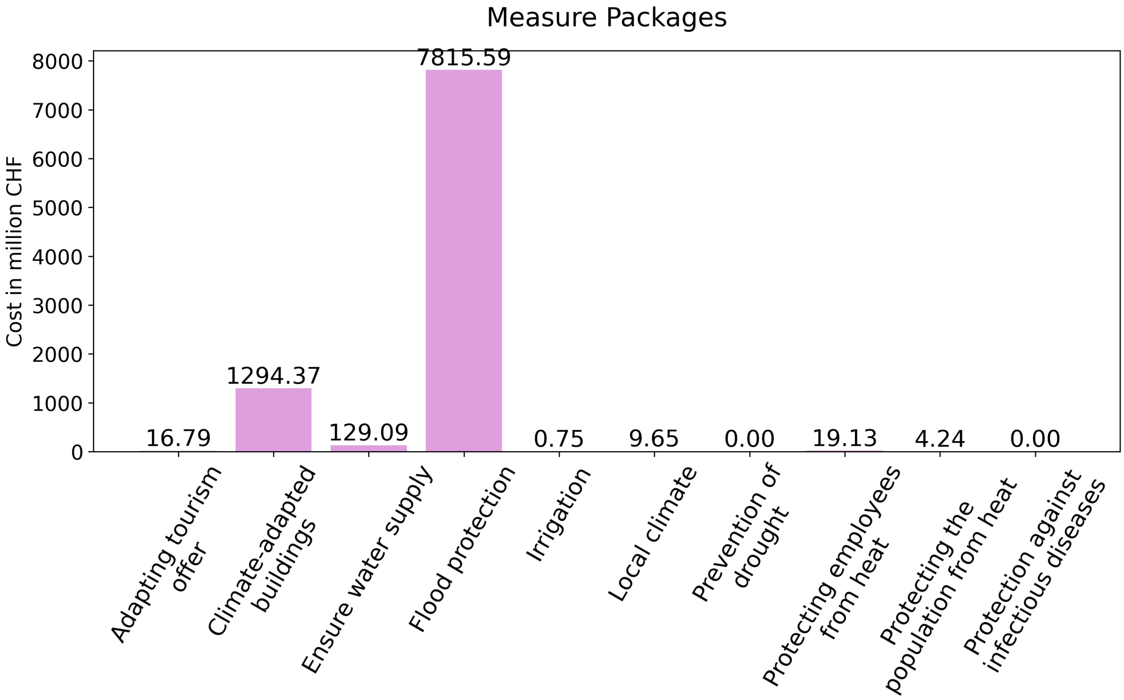


Figure 5.32: Investment Cost by Measure Packages without the three overlapping measures for cooling installations and summer thermal protection.

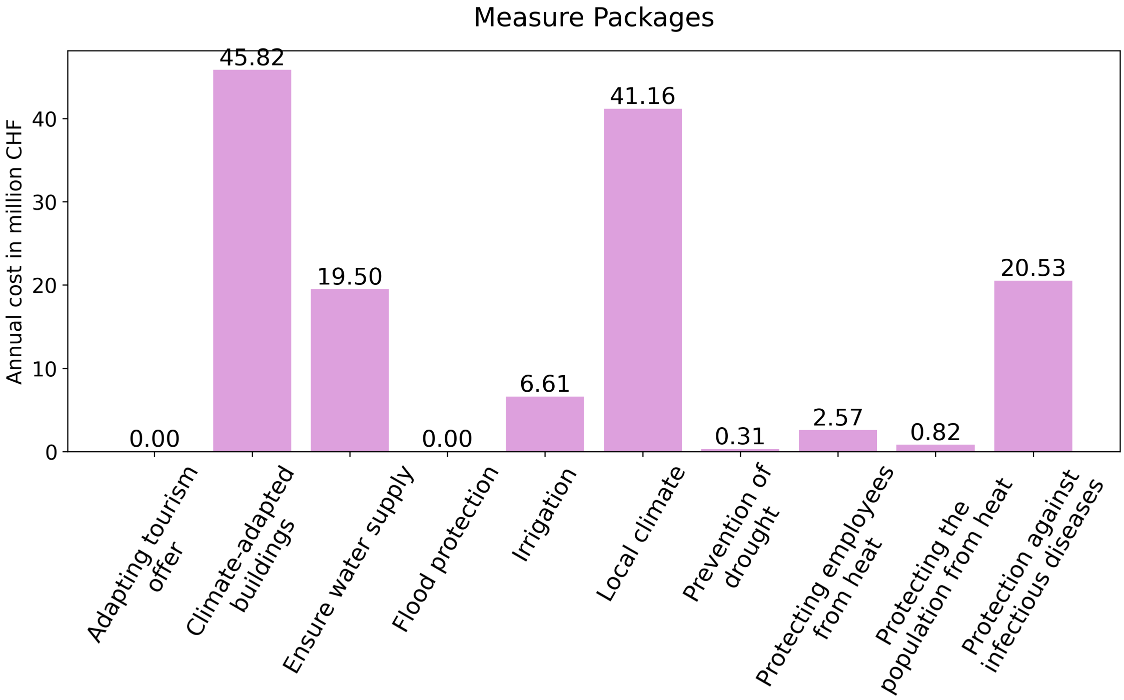


Figure 5.33: Annual Cost by Measure Packages without the three overlapping measures for cooling installations and summer thermal protection.

6. Discussion

To mitigate the effects of climate change, Switzerland has created a strategy for adaptation to climate change in 2012 (FOEN 2012). The first and second action plan on climate adaption result from that strategy (Swiss Confederation 2014, 2020). This thesis contributes to the project 'Costs of climate change impacts in Switzerland with and without successful global climate change mitigation' which is part of the NCCS-Impacts program 'Decision Support for Dealing with Climate Change in Switzerland: a cross-sectoral approach' lasting from 2022 to 2025.
To answer the research questions (Section 1.2), a database with climate adaptation measures was created. For each measure, proxies for the qualitative assessment of the feasibility and effectiveness were defined and scored with low, medium, or high within an expert assessment. In the database, the measures can be sorted by actor addressing the third research question. For the cost assessment, a selection of measures was decided on to calculated the cost of implementation across Switzerland.

The database developed from this thesis is essentially the first of its kind, cataloging climate change adaptation measures for eleven different risks across all of Switzerland. Nevertheless, the database at its current state is not complete, as it is part of an ongoing process. It should be considered as a starting point for further analyses and additions of measures, risks, or other categories which are not yet present in the database.

6.1 Characteristics of the Measures

The word cloud in Figure 5.1 clearly shows that the most important terms for adaptation are "heat" and "water". This is not surprising, considering the vast amount of literature looking into the effects of heat on human health and the development of heatwaves in the future (e.g. Baccini et al. 2011; Lee, Röösli, & Ragettli 2021; Ragettli et al. 2023; Stalhandske et al. 2022) or the effectiveness of heat warning

systems (e.g. Åström et al. 2017; Rötzer et al. 2019; Taylor et al. 2018). Similarly, drought risk increases under future climates scenarios, calling for adaptation measures to reduce the effects of water scarcity on the population, in agriculture, and for electricity production (e.g. Brunner et al. 2019; Hao et al. 2015; Scheben, Yuan, & Edwards 2016; Stavenhagen, Buurman, & Tortajada 2018). Hence, the prevailing terms of "heat" and "water" in the word cloud represent the urgency and importance of climate adaptation measures in these risks.
"Development" and "Protection system" are additional terms often mentioned in the database, showing the need to develop new concepts and plans for heatwaves or natural hazards, and implement new technological or structural measures to protect the population from heat, floods, or other risks. A study from Xu et al. (2015) shows the changes in the interdisciplinary topics of climate change research and in renewable energy research. There, "water", "management", "development", and "future health" are within the most used terms as well.
Further, measures using "Information" and "awareness raising" to distribute knowledge of climate risks are the most common in this dataset with 75 measures in "Communication" and 49 for "Concept and strategy" (Figure 5.2). In the IPCC AR6 chapter 13 "Europe", informational adaption actions is the largest group with 171 actions and 52 educational actions (Bednar-Friedl et al. 2022). Adaptation activities leading to behavioral changes (171) or information (119) are the second and third largest frequency for adaptation actions found by Owen (2020).

The database includes 236 climate change adaptation measures targeting eleven different risks, addressed by six actors, and intended for six target audiences. Some measures are listed multiple times across different actors or target audiences, resulting in 105 unique measures. In previous studies, about the same number of measures were analysed. Owen (2020) categorized 110 adaptation initiatives. Singh et al. (2020) stated that the IPCC AR5 lists approximately 121 adaptation options and used 68 options for his own assessment. The Europe Chapter in the IPCC AR6 analysed 27 adaptation measures to reduce heat-related impacts and risks to human health and seven for the thermal comfort in cities and buildings (Bednar-Friedl et al. 2022). This database contains 60 heat-health-related measures, by far the highest number. This might be due to the high damage potential to economy, ecology, and society during heat waves. However, only 16 measures are unique. In addition, there are 33 measures to reduce productivity losses at work (5 unique). Studies on the economic effect show that heat-related productivity loss has a sig-

nificant impact on markets (Day et al. 2019). Considering the high economic costs of heat-related loss of productivity today (CHF 665 million per year, Stalhandske et al. 2022) and in future climate (expected to triple, Stalhandske et al. 2022), it is no surprise that measures reducing said losses are numerous. Similarly, due the the impacts on mortality and morbidity, which are expected to double with significant difference between scenarios with and without adaptation, calls for additional adaptation actions are frequent and a must to maintain current levels of heat-related mortality (Åström et al. 2017; Díaz et al. 2019; Stalhandske et al. 2022).
To combat flood risks (FL-Dmg) from rivers and rainfall events, the database comprises 39 adaptation measures with 16 of them being unique. The large number of possible adaptation options showcases the importance to mitigate potential damage to economy, ecology, and society. The IPCC AR6 Europe Chapter lists three options each for flooding by river and pluvial floods (Bednar-Friedl et al. 2022).

The database lists 99 solutions to be implemented by cantonal authorities. Given Switzerland's federalist system, this is not surprising, as each canton has a significant degree of self-governance. This high number can be attributed to the various measures aimed at the public and in public spaces, such as the planning of outdoor areas. The five measures which can be implemented by individuals and private households is a stark contrast to the total of 192 measures from federal, cantonal, and municipal authorities. This large gap might be due to the origin of the measures from cantonal plans for climate adaptation (e.g. Thurgau 2022; Ticino 2022; Zurich 2018). Wachinger et al. (2013) found that individuals rarely take appropriate preparedness actions, even when they have experience and a high risk perception. According to them, this is due to one of three behavioural patterns:

1. Experience and motivation: Individuals choose to accept the risk due to the fact that the benefits outweigh the potential negative impacts.
2. Trust and responsibility: The responsibility lies with someone else to take action against the risk.
3. Personal ability: Individuals have little resources to affect their own situation.

Hence, it might be a strong point of the database to have the federal, cantonal, and municipal authorities do the vast majority of adaptation measures.

6.1.1 Co-occurrences and Associations

Figure 5.4 shows a clear picture of the distribution of the adaptation solutions by actor and risk. Measures to be addressed by governmental authorities are prevailing in the database, suggesting a crucial role in reducing impacts on climate change. Previous studies also reported that the focus mostly is on formal decision makers and governmental support or funding (Hötte & Jee 2022; Nalau & Cobb 2022). Further, implementing large-scale measures are typically done by governmental authorities (van Valkengoed & Steg 2019). Given the amount of adaptation measures at governmental levels, the Chi-square statistics of the correlation with significant combinations surprisingly does not show any combination of addressed risks and federal authorities (Figure A.4). "Corporations" show a high relevance with the ascending snowfall line (Chi-square value of 10.5, Figure 5.8), suggesting that they are highly affected by or involved in addressing this specific risk. Indeed, most of the measures are about changing tourist infrastructure or adapting strategies for marketing.

The entire population is the primary beneficiary as the majority of measures are aimed towards this target audience (Figure 5.5). This indicates that the risks are considered to impact the general population broadly, and measures are designed to benefit everyone. "Corporations" are a key target audience, indicating that targeted communication and strategies toward them could enhance adaptation success. These findings provide a foundation for developing effective and feasible adaptation strategies, ensuring that measures are designed to benefit the appropriate target audiences.

Figure 5.6 presents that many measures utilize "Communication" as implementation strategy. "Communication" means that people have to implement the measures themselves. This emphasizes the importance of informing the public about risks and adaptation options. With 31 measures focusing on the communication of "heat-related impairments of human health" (HE-Health), prediction in the increase of mortality and morbidity in future climates are taken serious (Ragettli et al. 2023; Stalhandske et al. 2022). Further, a study from Kalkstein and Sheridan (2007) showed that an increased perception of the risk enhances the response to warnings. Commonly, many studies gather the most measures in communication, information, or concepts and strategies, thus building a consistent knowledge base is an important part of climate change adaptation (Bednar-Friedl et al. 2022; Mattern & Jol 2018; Owen 2020). Hence, the strategic planning in adaptation efforts is highly important.

Figure 5.7, presenting the co-occurrences of the measure packages with the risks, shows a dependence of the measure package from the risk. Only the "Climate-adapted buildings" package addresses multiple risks. Since measure packages group actions with similar goals, this dependency is intentional.

6.2 Feasibility and Effectiveness

The feasibility of adaptation measures is generally high across the different categories (Figure 5.17). Adapting to the impacts of climate change in winter tourism seems to be the least feasible (SL-Yield, Figure 5.12). This is in line with the findings of Vaghefi et al. (2021) where they state that only ski resorts above 1800-2000 m elevation will survive.

"Harvest losses in agriculture due to drought" (DR-Agri) and "Water scarcity" (DR-Water) have a moderate feasibility score of 2.6, indicating the complexity of managing water resources for agriculture and society.

The feasibility of heat-related "Cooling energy demand" (HE-Cool) is 2.5, indicating certain variability in the proxies. Measures received low or medium scores in "Sustainability", "Flexibility", and "Maladaptation".

Measures addressed by the "Federal Government", "Cantonal", and "Municipal levels" have a higher feasibility (Figure 5.13). Governmental authorities have more available resources and regulatory powers to implement large-scale infrastructure (van Valkengoed & Steg 2019). In addition, most of the measures are to inform and sensitise the population, architects, or other professions. Wide-spread awareness campaigns are mostly done by federal, cantonal, or municipal authorities. The high involvement at the "Cantonal" and "Municipal levels" suggest feasible local implementation. Measures to be implemented by "Private" have a relatively low feasibility with a score of 2.4 which could be due to limited resources or a lack of regulatory incentives. Such regulatory incentives increase the willingness to implement certain measures in households such as moving laundry machines to higher floors to reduce flood damages (Botzen, Aerts, & van den Bergh 2009).

"Technical implementation" has the lowest feasibility (Figure 5.14). However, the significance of this finding is low since there are only four measures using technical implementations (Figure 5.2).

For most of the measures, the general population is the beneficiary, suggesting broad social acceptability (see Figure 5.15). As many elderly and people with chronic illnesses do not consider themselves to be old or at risk (Abrahamson et al. 2009),

measures aimed at the "Entire population" might bare higher feasibility and effectiveness. Nevertheless, measures specifically aimed at "Vulnerable groups" also get a high feasibility score of 3.0 (Figure 5.15). This might come from the fact, that most of these measures are communication or concept based such a telephone helpline or a buddy system to take care of vulnerable people.
Figure 5.16 illustrates that measures like "Control of pests," "Ensuring hydropower production," and "Protecting employees from heat" have high feasibility scores. Changing working hours to avoid the hottest parts of the day or year and breaks to drink water, are effective measures to reduce risk in high-intensity outdoor workers (Day et al. 2019). In contrast, "Artificial snowmaking" has a low to medium feasibility score, reflecting the practical challenges in its implementation.

Although most measures have a high feasibility, the effectiveness is low or medium at best for many of them (Figure 5.22). Hence, there is a clear mismatch between feasible and effective measures. The robustness scores are generally higher than effectiveness scores, indicating that the measures are resilient but may vary in immediate impact. A majority of the measures are "Communication" and "Concept and strategy", hence, information and sensitisation of the public or professionals. According to Wachinger et al. (2013), individuals often do not take appropriate preparedness actions, even when they have a high perception of the risks. Additionally, knowing about the risks of heat or drought does not change the circumstances. Hence, there is limited power and possibilities in awareness and information campaigns. In contrast, the robustness for such measures is high as adapting the communication strategy to different climate scenarios is fast and cost-efficient.

In the following subsections, a couple of measures from each opportunity get a closer look in terms of their effectiveness and feasibility by comparing them with existing literature.

6.2.1 Greater Heat Stress

Generally, the feasibility for measures targeting the opportunity "Greater heat stress" got high scores (Figure 5.12). The effectiveness, however, is low for most of them while the robustness is medium to high (Figure 5.18). This difference can be explained by the nature of the measures being mostly about sensitisation (e.g. MeasureID: F_Pop_ProtPop_HE-Health_2). Sensitisation does only have a limited effect on the temperature in buildings or outdoor spaces. For example, closing

shutters has a great potential to reduce mortality as this leads to a reduction of temperatures in buildings (Taylor et al. 2018). By informing the population about such actions the effects of heat can be reduced. Elderly are less likely to respond to recommended home and personal protection measures (e.g., use of sunscreen or air conditioners) compared to younger age groups (Khare et al. 2015). Only a minority of respondents were aware of their increased vulnerability to heat due to medical conditions or medications. Additionally, even when they had knowledge of the effects of heat on their illness and vulnerability, they did not apply this knowledge to themselves (Abrahamson et al. 2009). These two examples show the varying effectiveness of awareness raising campaigns.
The actor with the lowest feasibility is "Part of the population" which in this risk mostly are employees. Especially outdoor workers are difficult to protect from the influence of heat and heat stress (e.g. MeasureID: Ct_PartPop_ProtEmp_HE-Prod_1). Possible measures include behavioural changes such as drinking water and shifting active hours to cooler parts of the day to reduce heat effects (Day et al. 2019) or create shading with mobile sunshades.
The effectiveness score for "Heat action plans" (MeasureID: Ct_Pop_Prot-Pop_HE-Health_13) in the database received a "medium" as it is only an indirect measure, hence, no structural or technological implementations. In the IPCC AR6 Europe Chapter, this measure was rated with a "high" (Bednar-Friedl et al. 2022). "Awareness campaigns for sports and youth associations" (MeasureID: Ct_CivSoc_Prot-Pop_HE-Health_1) is a measure in the database which might be an effective measure. Khare et al. (2015) found that 60% of the 18-25 year old report suffering from headaches and sunburns. Measures such as "Distribution of water" (MeasureID: M_Pop_ProtPop_HE-Health_4) and "Telephone helpline" (MeasureID: Ct_VulGr_ProtPop_HE-Health_3) or "Buddy system" (MeasureID: M_VulGr-_ProtPop_HE-Health_2) reduce heat-related illnesses and increase the awareness of knowing whom to contact for assistance (Hasan et al. 2021).

HWSs (MeasureID: Ct_Pop_ProtPop_HE-Health_8) received a high score for the feasibility, robustness and effectiveness. Previous studies found that HWSs are effective in reducing mortality and morbidity (Chau, Chan, & Woo 2009; Fouillet et al. 2008; Morabito et al. 2012; S. Williams et al. 2022). Ebi et al. (2004) found that HWSs are highly cost-efficient with costs of $ 210'000 to run the system for saving 117 lives with a VoSL for each life of $ 4 million. With an activation cost of about $ 366'000 (AU$ 593'000) for 1 week, S. Williams et al. (2022) calculated costs of similar magnitude. The perceived threat of danger is a significant factor for the effectiveness of a HWS (Toloo et al. 2013). Responses to heat warnings are increased with higher perception of the risk (Kalkstein & Sheridan 2007). Hence, implementing HWSs is more effective if it is combined with awareness campaigns and sensitisation to heat stress.

"Adapting buildings to heat" are important measures to reduce heat stress and prevent mortality and morbidity, especially in an aging population (Åström et al. 2017). One such measure could be to close shutters on buildings to keep the temperatures low (Taylor et al. 2018). According to Vaghefi et al. (2022), measures that target night time temperatures have a bigger impact. Hence, the adaptation options should focus on reducing temperature at night. To bring people to implement cooling systems (MeasureID: P_PartPop_CliBui_HE-Cool_1) or other protective measures against heat (MeasureID: P_Pop_CliBui_HE-Health_2), psychological factors are more important than socioeconomic circumstances (Murtagh, Gatersleben, & Fife-Schaw 2019), indicating that informing the population about the risks of heat stress has a significant role.

"Consideration of local climatic aspects in outdoor space design and area development" (MeasureID: Ct_PubHand_LocCli_HE-Health_2) is an important tool to reduce the urban heat island effect. Creating green spaces and plant trees in urban areas (Figure 6.1) can help to mitigate the negative effects of climate change through shading and cooling (Rötzer et al. 2019). However, this measure was only assess with a low score in effectiveness as the green spaces and trees have a limited radius of effect. In addition, the flexibility is medium since changing or increasing green areas is expensive and might need additional planning. To reduce heat stress in urban areas, the use of white tar would be an effective measure to reduce surface and air temperatures (Vujovic et al. 2021). Due to the reduced heat, thermal expansion reduces, effectively increasing the lifespan of tar and reducing maintenance. White rails could be used as well. However, these measure are not yet in the database. The consideration of local climatic aspects might reach its limit for high warming when more and more areas might become unsuitable. Hence, the robustness is not given for every climate scenario.

Figure 6.1: Newly built green space at Neuwiesen, Winterthur for cooling and biodiversity.

6.2.2 Flood Risks and Damages

To mitigate the effects of heavy rainfall events, various measures for "Water retention" are listed in the database, namely "Unsealing of surfaces" (e.g. permeable pavements), "Stream revitalization with retention", "Retention structures in residential areas" (e.g. rain barrels), and "Underground buffer storage", and "Green roofs". Due to the continuous sealing of surfaces, urban flood volumes will increase non-linearly with increasing rainfall intensity in future climate (Sun et al. 2021).

"Unsealing of surfaces" (MeasureID: M_Pop_WatRet_FL-Dmg_1) and "Stream revitalization with retention" (MeasureID: M_Pop_WatRet_FL-Dmg_3) have a high effectiveness due to the large area covered. Restoration of wetlands and floodplains are buffers for precipitation events, hence, regulate floods, and have significant co-benefits in biodiversity and water supply (Iacob et al. 2014).

To increase "Property protection", long-term measures are more effective than temporary ones (MeasureID: M_Pop_PropProt_FL-Dmg_2). Such measures could be to replace floor types that are vulnerable to flooding with a tile floor or move the laundry, dryer, and heating system to a higher level floor (Botzen, Aerts, & van den Bergh 2009). The overall feasibility of this measure is medium to high, primarily due to the high financial costs, which are not affordable for every household. Here, incentives in the insurance premium can increase the willingness of the population to take mitigation actions (Botzen, Aerts, & van den Bergh 2009).

Measures about "Risk-based spatial planning" have a low effectiveness (1.2) and a high feasibility (2.9). According to Kreibich et al. (2015), the contribution to risk mitigation for flood zoning and land-use planning is often low.

"Green roofs" (MeasureID: P_Pop_WatRet_FL-Dmg_1) have low effectiveness when implemented alone. Using green roofs (Figure 6.2) for rooftop runoff (bio-retention only) offers limited water retention potential, as roof areas are typically too small to have a significant impact (Ahiablame & Shakya 2016). "Rain barrels" (MeasureID: M_Pop_WatRet_FL-Dmg_4) to catch the runoff from roofs are more efficient than green roofs. However, both measures alone are not sufficient to reduce flood events (Ahiablame & Shakya 2016).

The so-called Low Impact Development (LID) practices, including permeable pavements, rainwater harvesting, green roofs, infiltration swales, and bio-retention areas, have demonstrated high effectiveness in reducing flood volumes and damages when used in combination (Ahiablame & Shakya 2016; Damodaram et al. 2010; Sun et al. 2021). Sun et al. (2021) states that prevention of floods is most effective by combining integrated flood management schemes with traditional drainage systems and LID.

Figure 6.2: A green roof reduces the runoff and provides space for plants and insects. (Image: Martin Weber)

6.2.3 Rising Snow Line

Measures to "Adapting tourism offer" have a medium to high feasibility and a high effectiveness and robustness (Figure 5.23). Most of the measure are "Concepts and strategies", "Communication", or "Financial support", which all can easily be adapted to new circumstances. However, the measures "Concentration of snow sport facilities in suitable locations" (MeasureID: Ct_Cor_AdTour_SL-Yield_1) and "Investments in new snow sport facilities at high altitudes" (MeasureID: Cor_PartPop_AdTour_SL-Yield_1) have medium robustness. The measures will already be needed for the RCP2.6 scenario. Regardless of the climate scenario, only ski resorts with ski lines above 1800-2000 m elevation will survive and every resort will suffer from winter tourism (Vaghefi et al. 2021). Additionally, the "Sustainability" and "Maladaptation" are medium. This is due to the strong negative effect of ski lifts and related winter sport activities on wildlife, for example on the black grouse cock (Coppes et al. 2017; Patthey et al. 2008). By shifting winter tourism to higher altitudes while simultaneously diversifying and increasing summer activities, the ecological consequences might be large (e.g. loss of habitable area). To counteract these losses, a reduction of recreation density in key habitats, establishing of undisturbed wildlife refuges, and a strip of dense understory for protection could be implemented (Coppes et al. 2017).

"Artificial snowmaking" (MeasureID: Cor_PartPop_ArtSnow_SL-Yield_1) has low to medium feasibility, as well as low robustness and effectiveness. In some cases, snowmaking is no longer suitable or effective, particularly for winter sports locations below 1800-2000 m elevation (Vaghefi et al. 2021).

6.2.4 Spread of Harmful Organisms, Diseases, and Alien Species

Adaptation options to reduce the impacts of "Harmful organisms, diseases, and alien species" have high feasibility and robustness, but a low or medium effectiveness (Figures 5.12, 5.18 for HO-Agri, HO-Forest, HO-Health). Almost all of the measures are "Communication", "Research", "Concepts", or "Monitoring". Especially, "Impairment of human health" (HO-Health) and "Impairment of forest services" (HO-Forest) have low effectiveness (score of 1.1). For these risks, there are only three structural measures. They try to minimize the mass proliferation of bark beetles with the implementation of silvicultural measures (MeasureID: Ct_Pop_ConPes_HO-Forest_1 and Cor_Pop_ConPes_HO-Forest_1), and remove standing water to control the spread of the tiger mosquito (MeasureID: Ct_Pop_ProtInf_HO-Health_1). Wilson et al. (2020) states that it is imperative to maintain vector control by investments and political will. Further, drainage and filling of ponds has been successful in the past. However, this can lead to potential maladaptation by negatively affecting pond-breeding species (e.g. frogs) (Rannap, Lõhmus, & Briggs 2010).

Rising temperatures and water scarcity can stress trees, leading to a reduction in their insect resistance mechanisms (Fettig et al. 2007). Also, a warm and dry environment is beneficial for the Eurasian spruce bark beetle (Netherer & Hammerbacher 2022). Rising temperatures and CO_2 levels accelerate insect metabolism, increasing the population density and leading to more damage and injury of crops and trees (Tonnang et al. 2022). Hence, preventing the spread of bark beetles and other pests become imperative in future climatic conditions. The measures in the database to control pests, however, have low effectiveness (Figure 5.23). Many measures are focusing on silvicultural measures, such as increasing the heterogeneity or thinning. Even though, thinning has been advocated as a preventive measures in the past, certain bark beetles are attracted to thinning (Fettig et al. 2007). Hence, foresters need to be educated on how to effectively prevent bark beetle spreading. Therefore, increasing the "Monitoring and early warning" to prevent outbreaks of vector born diseases, pests, or invasive species is crucial to mitigate losses and damages in forest services and agriculture. An effective measure to increase preparedness and response is to enhance the collaboration between the public health sector and veterinary surveillance (Lindgren et al. 2012).

The measure package "Climate-adapted cultivation" combines measures to reduce and mitigate effects of climate change on agriculture. One specific measure is the "Genetic adaptation of crops" (MeasureID: Uni_Cor_CliCult_HO-Agri_1). While genetic engineering improves the sustainability of Swiss agriculture and accelerates the production of climate-adapted crops, the process to do so remains expensive (Scheben, Yuan, & Edwards 2016; SCNAT 2013). In addition, a risk of maladaptation exists as replacing sensitive crops with more resilient ones may impact the diversity of crops used in agriculture (Agnolucci et al. 2020).

6.2.5 Drought

Measures to mitigate the risk of drought-related "Harvest losses in agriculture" (DR-Agri) achieve a medium to high feasibility (score of 2.6, Figure 5.12), a high robustness (score of 2.8), but a low effectiveness (score of 1.4, Figure 5.18). The Swiss Plateau, where the majority of Swiss agricultural land is located, is the main region affected by water scarcity (Brunner et al. 2019). Hence, adaptation measures are necessary to keep the current level of agriculture. Such measures could be the choice of drought-resistant crop types (MeasureID: Ct_Cor_CliCult_DR-Agri_1), improved irrigation techniques (MeasureID: Cor_Cor_Irri_DR-Agri_1), and public awareness campaigns (MeasureID: Ct_Cor_PrevDro_DR-Agri_1) (Brunner et al. 2019). As with more resilient crops to diseases and pests, using drought-resistant crops could lead to losses in agricultural biodiversity (Agnolucci et al. 2020). A study in Germany in 2012 found that the benefit-cost ratio of using adapted crop types is up to 680:1, suggesting very high cost-efficiency (Tröltzsch et al. 2012). In contrast, irrigation of agricultural land shows low effectiveness and acceptability with high costs for irrigation (0.2-1:1 benefit-cost ratio). However, certain plant varieties (e.g. fruits, potatoes, sugar beets) can only be cultivated with irrigation. The construction of water storage systems for rainwater (Figure 6.3) and new reservoirs (MeasureID: Cor_Cor_PrevDro_DR-Agri_2) can alleviate water shortages, especially in combination with a reduction of irrigation water demand (Brunner et al. 2019; Hao et al. 2015). The rainwater reservoirs could catch the water in winter to be used in summer.

Figure 6.3: A rain water barrel placed into the garden. It stores 6500 L of water which is enough to water the garden for two weeks during a drought. (Image: Martin Weber)

The shift in the temperature regime and higher summer temperature increase the stress on crops. To mitigate impacts of drought in agriculture, an adaption measure could be the shift to winter wheat. This might even lead to increasing yields, at least until 2040 (Hayman et al. 2024). In the database, the measure states to also adapt the cultivation system ("Choice of crops and varieties as well as cultivation system according to water availability", MeasureID: Cor_Pop_CliCult_DR-Agri_1).

Climate change is expected to induce a shift in precipitation patterns and alter runoff regimes (Brunner et al. 2019; CH2018 2018; Hakala et al. 2020; Savelsberg et al. 2018). Hakala et al. (2020) found that the reduction in summer inflow is 30% under RCP4.5 and 50% for RCP8.5. This has significant consequences on Swiss hydroelectricity companies and electricity production (DR-Elec). The water availability for hydropower production is expected to increase in winter when energy prices are higher due to heating (Brunner et al. 2019; Savelsberg et al. 2018). From this regime shift, run-of-river power plants benefit more because of their inflexibility, as more flexible storage power plants already capitalize on peak price hours (Savelsberg et al. 2018). The measures in the database only show a low effectiveness (score of 1.3, Figure 5.18), but high robustness (score of 3.0, Figure 5.18) and feasibility (score of 2.8, Figure 5.12). The measures include "Communication", "Research" and "Process-oriented changes" which do not provide any inputs on technological or structural enhancements.

To mitigate impacts of "Water scarcity" (DR-Water), the database lists 25 measures. With a feasibility of 2.6 (Figure 5.12), a robustness of 2.9 (Figure 5.18), and effectiveness of 2.2 (Figure 5.18), the overall scores are relatively high. The measure package "Ensure water supply" has a medium to high effectiveness score of 2.4, making it the second most efficient measure package. The lack of water in summer can partially be softened by reservoirs and regulated lakes to store water in winter (Brunner et al. 2019). This measure also provides significant co-benefits for water retention, helping to reduce flood risks. A specific measure is to cross-link the water supply, connecting regions and municipalities. This increases water security when not the whole storage capacity can be used, making greater use of installed capacities (Brunner et al. 2019; Zafra-Gómez et al. 2020). However, the financial affordability is medium as connecting municipalities can be costly and direct management is more cost-efficient than inter-municipal cooperation (Zafra-Gómez et al. 2020). Under a continuous drought, measure which increase the water supply have limited effects on water availability. Hence, reducing water use is essential during extended droughts.

The measure package "Reduction of water consumption" has a medium effectiveness (score of 2.3, Figure 5.23). The measure "Reduction of water consumption" (MeasureID: P_Pop_RedWat_DR-Water_1) is a communication and a process-oriented measure. Promoting water-saving technologies to reduce the water consumption achieved the second highest rating in the effect of different policies in a study from Stavenhagen, Buurman, and Tortajada (2018). This finding is supported by Lallana et al. (2001) where they state that domestic water-saving devices (e.g. low-flow toilets) and garden irrigation significantly reduce water use. As per Inman and Jeffrey (2006), media broadcasts reduce water use only temporarily by 2-5%. Individual water meters, rapid leak detection meters, public awareness campaigns, and municipal regulations obtained the third highest rating (Stavenhagen, Buurman, & Tortajada 2018) and metering reduces water consumption by 10-25% (Inman & Jeffrey 2006; Lallana et al. 2001). Another measure in the database is to adjust water pricing policy based on water availability (MeasureID: M_Pop_RedWat_DR-Water_1). According to Damodaram et al. (2010) and Lallana et al. (2001), higher water prizes reduce water consumption. However, water prizing strategies are only effective in the beginning. With time, the population get accustomed to higher prizes, eventually offsetting the effect (Stavenhagen, Buurman, & Tortajada 2018).

6.3 Cost Database

As there are very few studies looking into the cost assessment of climate adaptation options, only about a fifth of the database got a quantitative number for the cost of implementation (48 measures). Comparing Figures 5.2 and 5.3 with Figures 5.24 and 5.25 shows that a couple of risks are missing in the cost assessment (DR-Elec, HO-Agri, and HO-Forest). None of the cantonal climate adaptation strategies analysed listed costs for measures against the "Spread of harmful organisms, diseases and alien species" (e.g. Thurgau 2022; Ticino 2022; Zurich 2018). Similarly, the actor "Universities" is missing. For the measure categories, only the "Process-oriented" measures is not present in the cost assessment database. The largest difference is in the measure package. Here, only 10 packages are represented in the cost assessment even though there are 22 packages in the database. Most of the package missing are related to agriculture (e.g. climate-adapted cultivation), forestry (e.g. prevention of pests), or water saving (e.g. water retention).

6.3.1 Cost Assessment

The database for the costs assessment comprises 48 measures in total. However, some measures ("Summer thermal protection (buildings)" and "Installation of cooling systems", see Figure A.2) have overlapping objectives. Hence, three out of the five measures were removed to prevent an artificial inflation of the costs. The cost assessment with the remaining 45 measures resulted in total investment costs of CHF 9.3 billion and annual costs of CHF 137 million. Using all measures in the cost database, the costs increase to CHF 36.2 billion (investment) and CHF 344 million (annual). Compared to Switzerland's total government expenditure in 2019 of CHF 238 billion, the estimated costs of CHF 9.3 billion may seem relatively small (FSO 2022). However, with current spending on environmental protection at CHF 4 billion, these additional costs would effectively triple the existing expenditures in this sector. In addition, looking only at the Federal budget in 2023 of CHF 81 billion, the additional costs would need a budget increase of 11% (FFA 2024). However, the additional costs are one-time investments and can be spread over multiple years to lower the impact on the Federal budget. In addition, some costs are borne by companies and private individuals.

Cost of recent damages through natural hazards and extreme events help to contextualise the costs found in this analysis. The heat extreme years 2018 and 2019 lead to total damage costs between 32 and 37 billion in Germany (Jan Trenczek & Oliver Lühr 2022). In Switzerland, floods, debris flows, landslides, and rockfalls lead to yearly costs of CHF 311 million (arithmetic mean over the entire inflation-adjusted data series from 1972 to 2022), with the median at CHF 103 million (Liechti & Badoux 2024). Therefore, the CHF 137 million annual costs for the measures is lower than the current expenditures for natural hazards alone, without including heat-related expenditures.

To sum it up, the investment and annual costs appear quite high, but with a closer look at the damage costs of current events, the adaptation measures will likely lead to a lower economic impact.

The investment costs associated with different "RiskIDs" reveal a significant disparity in resource allocation (Figure 5.26). The staggering CHF 7,8 billion for flood protection makes it a top priority in the risk management strategy, even though there are no annual costs. This significant investment reflects the high potential impact, likely driven by the severe consequences of flooding events. In the report 'What risks endanger Switzerland?' by the FOCP, floods have the highest aggregated damage costs out of the risks used in this thesis (FOCP 2020). According to Liechti and Badoux (2024), the mean annual damage costs from 1972 to 2022 for floods and debris flows makes 92% of the total damage costs (CHF 311 million), which is CHF 286 million. Once the protective measures are in place, they require minimal maintenance, making the one-time investment a cost-effective long-term

strategy.
In contrast, the high annual costs for heat-related "Impairment of human health" (He-Health) and "Cooling energy demand" (HE-Cool) underscore the continuous nature of these challenges and indicate the importance of the recurring measures. For example the HWS generates yearly costs of at least CHF 150'000 for a one-week activation with a benefit-cost ratio of 2.0 - 3.3 (S. Williams et al. 2022). This number is likely to be higher as the cost of living in Switzerland differs from Australia.
The relatively low investment and annual costs for agriculture and water-related risks suggest a lower perceived risk level. The increasing frequency and intensity of droughts might force a re-evaluation to ensure adequate resource allocation.

This concentration of costs at the cantonal level likely reflects the scale of infrastructure projects, such as "Flood protection" and "Climate-adapted buildings", which are typically managed by this level of government as well as public welfare projects. In contrast, private actors have minimal investment costs, suggesting either a lower expected contribution or fewer responsibilities in large-scale adaptation projects.
The abundance of yearly costs in private sector suggests the longevity of the investments. The annual costs at the "Cantonal level", amounting to CHF 52.31 million, are moderate when compared to the funding allocated for renewable energy and energy efficiency, which ranges between CHF 10-12 million per year in the Canton of Thurgau (Thurgau 2022).

The high costs for "Structural implementations" suggests that significant upfront investments in physical infrastructure is needed for adaptation (Figure 5.30). Most of the costs comes from the risk FL-Dmg with its "Implementation of hydraulic engineering concept" (MeasureID: Ct_Pop_FlProt_FL-Dmg_1) measure in the measure package "Flood protection". With the increasing heat in cities and the expected increase of flooding, structural measures are needed to reduce the impacts of heat-waves and strong rainfalls or flood events (Stalhandske et al. 2022; Sun et al. 2021; Taylor et al. 2018; Tradowsky et al. 2023).
The high annual costs for financial support are attributed to the fact that subsidies will be sustained over several years (e.g. financial support in Ticino 2022). Most measures in "Communication" have to be done every year, leading to relatively high annual costs. One example is the "Communication of heat warning" (MeasureID: Ct_Pop_ProtPop_HE-Health_8) which is needed every year to show its effect (Ebi

et al. 2004; Toloo et al. 2013; S. Williams et al. 2022). The high annual costs for the "Structural implementation" has to do with the maintenance of the built infrastructure as well as additional costs for the energy requirement.

The CHF 7.8 billion for "Flood protection" (5.32) dwarfs other expenses. This number is exactly the same as for the risk FL-Dmg in Figure 5.26 as there is only one measure in the cost database for this risk. Nevertheless, this states the importance of flood protection under future climate (Ahiablame & Shakya 2016; Kreibich et al. 2015). With CHF 1.3 billion for "Climate-adapted buildings" shows the necessity of heat protection. To force the implementation of heat-reduction measures, psychological factors such as threat and coping appraisals are the strongest factors affecting the intention to protect ones home from overheating. In addition, a high prevalence of air conditioning lowers heat vulnerability (Murtagh, Gatersleben, & Fife-Schaw 2019). As heat-related mortality is expected to double under RCP8.5, resulting in an estimated 1300 deaths per year compared to 658 today, the installation of cooling systems becomes essential (Stalhandske et al. 2022). In Switzerland, the VoSL is CHF 7.2 million, equating to CHF 259'000 per lost year of life (Value of a lost year of life (VLYL)) (ARE 2023). This doubling in heat-related mortality would lead to an additional 650 deaths annually, incurring costs of CHF 4.68 billion, or CHF 169 million per lost year of life.
The high annual costs for "Climate-adapted buildings" is due to communication and sensitisation efforts as well as subsidies and financial support. For the "Local climate", the annual costs are mainly caused by the measure "Urban planning measures to reduce heat accumulation and heat islands" with CHF 34.5 million (MeasureID: M_Pop_LocCli_HE-Health_1). Interestingly, the package "Protection against infectious diseases" has annual costs of CHF 20.53 million but no investment costs. Its measures are either monitoring or sensitisation which explains the abundance of investment costs and the relatively large annual expenses.

6.4 Limitations, Difficulties, and Gaps

To create the adaptation database, the found measures had to be filtered to be relevant for Switzerland. This process might have led to subjective selection of adaptation measures. The expert judgement used in the feasibility assessment might not fully represent the stakeholder groups nor the political and social factors. To

choose the climate adaptation measures, previous studies and predictions of future climates were used. However, Vautard et al. (2023) found that heat extremes in Western Europe increased faster than predicted by models. They caution against relying too heavily on climate model projections for adaptation plans. In a new study, Juhola et al. (2024) emphasizes that there is a limit to adaptation and that those limits are not yet fully understood. Adaptive management of floods in future climates may become increasingly difficult, potentially rendering future disasters unmanageable (Kreibich et al. 2015). A challenge for Swiss climate adaptation plans is the diversity in topography and regional differences. For instance, adapting to increased heat stress necessitates regional flexibility, as maintaining current levels of heat-related mortality exhibits greater variation between regions than between different RCP scenarios (Åström et al. 2017).
Only one risk, the "Impairment of human health due to heat stress" (HE-Health), has measures specifically aimed at vulnerable groups. Further measures aimed at vulnerable groups could be provided, for example in case of flooding (e.g. evacuating movement impaired people) or at the work place.

In the cost assessment, difficulties arose while looking for the costs of the adaption measures. There are only very few studies looking into costs of climate change adaption measures. Costs were mostly found in cantonal plans which can not be directly transferred to corporate or household level. Further, the discount rate of 0%, as it is in the project guidelines, does not present reality, but is an easy way to depict costs and present them in today's setting. Most of the costs are on a cantonal level or smaller. Hence, they had to be extrapolated for a nationwide cost assessment. In this process, several assumptions were made such as the estimation of buildings that need cooling. Most of the interpolations were done with some assumptions such as the linear interpolation from cantonal to national level, for example in the up-scaling with the population or area.

For certain risks (e.g. HO-Health, HO-Forest, DR-Agri, DR-Water), there is potential to add more adaptation measures to the database to increase the relevance, especially for structural and technical implementations. "Impairment of human health by the spread of harmful diseases" (HO-Health) and "Impairment of forest services by the spread of organisms and alien species" (HO-Forest) have low effectiveness due to measures solely promoting sensitisation and monitoring (Figure 5.18).

White tar and rails should be added to the database as structural measures for the risk "Impairment of human health by greater heat stress" (HE-Health). They reduce heat stress in urban areas by reducing surface and air temperatures due to the higher reflectance (Vujovic et al. 2021).
Agroforestry shows a promising ability to protect crops from climate extremes, reducing the effects of heat and drought and offers protection from storms (Quandt, Neufeldt, & Gorman 2023). However, there is no measure promoting agroforestry. Increases in biodiversity is a positive side effect. Using agrivoltaic to shade crops reduces water stress and heat extreme due to shading (Amaducci, Yin, & Colauzzi 2018). Moreover, it would increase electricity production. However, both measures are not yet in the database and should be added for the risk "Harvest loss in agriculture due to increasing drought" (DR-Agri) or "Water scarcity" (DR-Agri).
Afforestation is highly effective in reducing flood peaks, reducing floods by 60-70% for complete forest coverage for small and frequent events (Iacob et al. 2014). However, this measure is not yet listed in the database and should be added to the "Increasing risk of flooding" (FL-Dmg).
The adaptation database is limited and should be considered a starting point that allows for the addition of further measures.

6.4.1 Future Research

In this thesis, a comprehensive database for climate change adaption measures in Switzerland was built. Nevertheless, this process is not finished as the database can be extended with additional measures or risks. Future research could focus on evaluating the effectiveness of the measures post-implementation to identify the most cost-efficient options. Further, studies about the effectiveness of the adaptation measures in the future could be done. A gap in the scientific literature is the cost of adaptation measures and benefit-cost analyses. Here, a comparison of the costs for climate adaptation measures with current damage costs and the reduction in damage costs after implementation can provide valuable insights into the economic efficiency and effectiveness of these measures.

7. Conclusion

The database developed through this thesis represents the first of its kind, stocktaking climate change adaptation measures for eleven distinct risks across all of Switzerland. However, it is important to note that the database is not yet complete, as it is part of an ongoing process. It should be viewed as a foundational starting point for further analyses and the inclusion of additional measures, risks, and other categories that are currently absent. This initial effort lays the groundwork for continuous updates and enhancements in the future.

The current database consists of 236 adaptation measures, categorizing them across the risks, various actors, target audiences, measure categories, and measure packages. The measures focus on mitigating heat-related risks, droughts and water scarcity, flood damage, and the spread of harmful organisms, diseases and alien species. These measures were gathered through an extensive literature research, including grey literature, and expert discussions. Also, inputs from stakeholders and from federal, cantonal, and municipal authorities were obtained through workshops. Figure 5.1 highlights "Water" and "Heat" as the most frequently used terms, underscoring the significance of heat- and water-related climate adaptation. Heat-related risks are particularly prevalent, accounting for 110 out of the 236 measures (HE-Health: 60, HE-Prod: 33, HE-Cool: 17), followed by drought with 44 measures (DR-Water: 25, DR-Agri: 16, DR-Elec: 3), and flood damage with 39 measures. The "Cantonal level" is identified as the primary actor responsible for implementing the adaptation measures, with 99 assigned measures. The "Federal Government" also bears a significant responsibility for implementing these measures. A substantial portion of the measures focuses on sensitization and awareness-raising, with 75 measures categorized under "Communication." Additionally, 49 measures in the "Concept and Strategy" category are aimed at creating and revising federal, cantonal, or municipal climate adaptation strategies. To address the impacts of climate change on human health and infrastructure, 44 measures are dedicated to structural interventions. The largest share of these measures is intended to benefit the "Entire population."

The feasibility assessment showed that most of the measures are highly feasible. The assessment was based on the 5 factors sustainability, financial viability, co-benefits, flexibility, and maladaptation. They act as proxies for the socio-political acceptability, economic, and environmental factor used by Singh et al. (2020) and IPCC (2022) (see Table 4.5).

The assessment of the feasibility and effectiveness of the measures revealed a significant discrepancy between the two for many of them. For example, while "Communication" measures are highly feasible, their effectiveness is generally lower, highlighting the need for complementary strategies to enhance their impact. "Communication" is strongly linked to increasing heat stress levels, highlighting the critical role of effective communication strategies in managing health risks associated with heat. However, the effectiveness of these strategies depends on the broad population's implementation of the recommendations. Only 33 measures were found to have high effectiveness, successfully reducing the impacts of climate change and mitigating damages. Robustness, which describes the positive impact of measures across different climate scenarios, achieved higher scores.

"Water scarcity" (DR-Water) and "Loss of income from winter tourism" (SL-Yield) got the highest effectiveness score, suggesting that the measures are suitable to mitigate the impacts of droughts and the loss of income from winter tourism. The effectiveness score of 2.5 for "Technical implementation" indicates that physical measures have a better chance of reducing climate impacts than other measure categories. Measures such as "Climate-adapted buildings" and "Ensuring hydropower production" are highly feasible and effective, making them top priorities for implementation. Adapting buildings to heat effectively reduces heat stress and prevents mortality and morbidity (Åström et al. 2017; Murtagh, Gatersleben, & Fife-Schaw 2019).

To enhance the success of adaptation measures, it is recommended to prioritize high-feasibility and high-effectiveness actions, such as "Climate-adapted buildings." Additionally, targeted support should be developed for less feasible but essential measures, like "Adapting tourism offers" or "Artificial snowmaking," to improve their viability. Collaborations between federal and cantonal authorities is crucial to optimize implementation, with careful attention to timing to ensure the measures' full impact.

The total estimated investment costs for the 45 measures is CHF 9.3 billion, with annual costs of CHF 137 million. Flood protection (FL-Dmg) alone constitutes CHF 7.8 billion of this investment. The "Cantonal level" bears the bulk of both one-time and annual costs. While these figures may seem high, they are likely justified when considering the potential reduction in damage costs. Comparing the costs of climate adaptation measures with current damage costs and the expected reduction post-implementation can offer valuable insights into their economic efficiency and effectiveness.

The adaptation measures identified and listed in this thesis are crucial for mitigating economic, societal, and ecological impacts of climate change in Switzerland. Most of the measures achieve a high feasibility, but only few measures have high effectiveness as well. While the costs of these measures appear substantial, they are justified when compared to the potential damage costs from climate-related events. Future research should focus on evaluating the post-implementation effectiveness of these measures and refining the cost assessment to ensure the efficient allocation of resources. This database serves as a foundation for the ongoing efforts to enhance climate resilience in Switzerland, with the potential for further expansion and refinement.

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A. Appendix

Table A.1: Costs categories with examples (Kreibich et al. 2014) (adapted from Parker, Green, & Thompson 1987).

	Tangible costs	**Intangible costs**
Damage costs including recovery costs arise during and after an event, as well as during the recovery phase	**Direct costs** Physical damage to assets: – buildings – contents – infrastructure	Loss of life Health effects Loss of environmental goods
	Business interruption costs Production interruption because of destroyed machinery	Ecosystem services interrupted
	Indirect costs Induced production losses of suppliers and customers of companies directly affected by the hazard	Inconvenience of post-flood recovery Increased vulnerability of survivors
Risk mitigation costs arise due to emergency response, planning (including risk analyses), and risk reduction	**Direct costs** Design and set-up of mitigation measures Operation and maintenance costs	Environmental damage – due to development of mitigative infrastructure – or due to a change in agricultural practices
	Indirect costs Induced costs in other sectors	

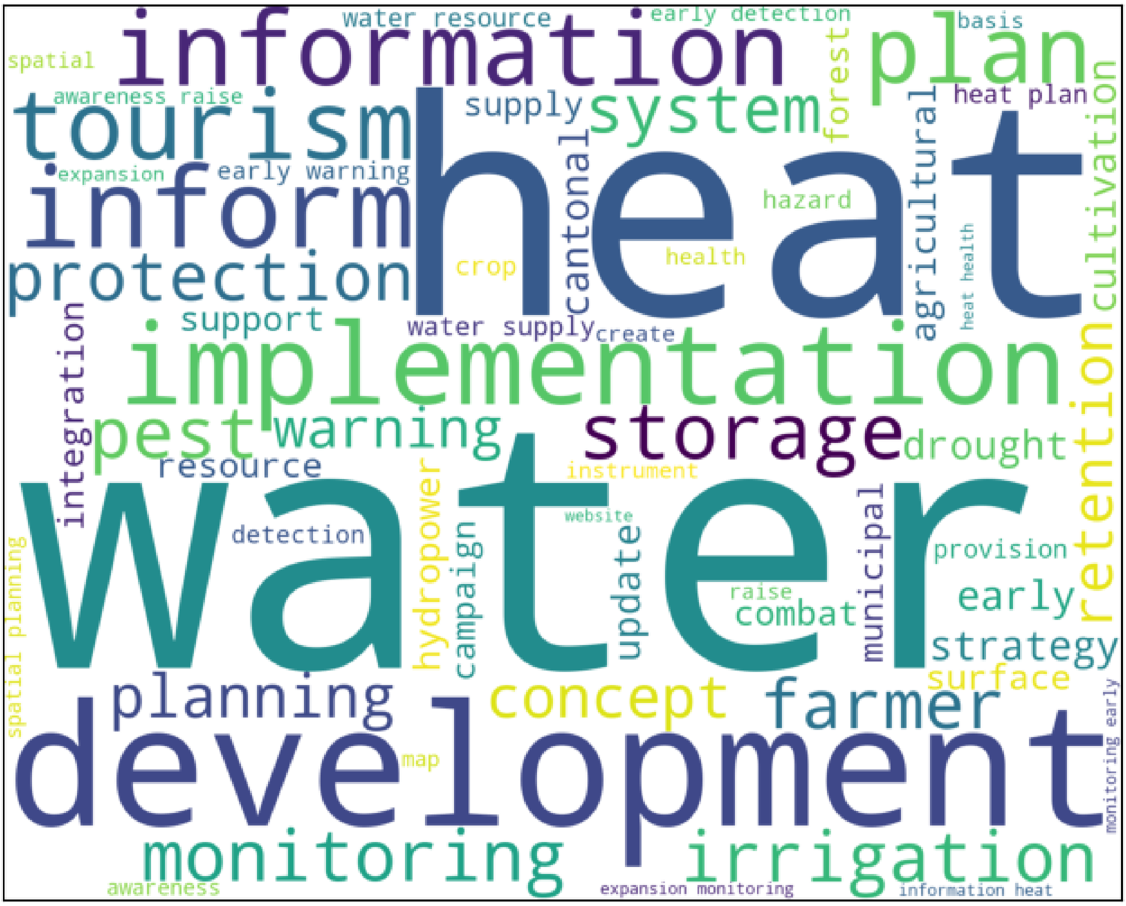
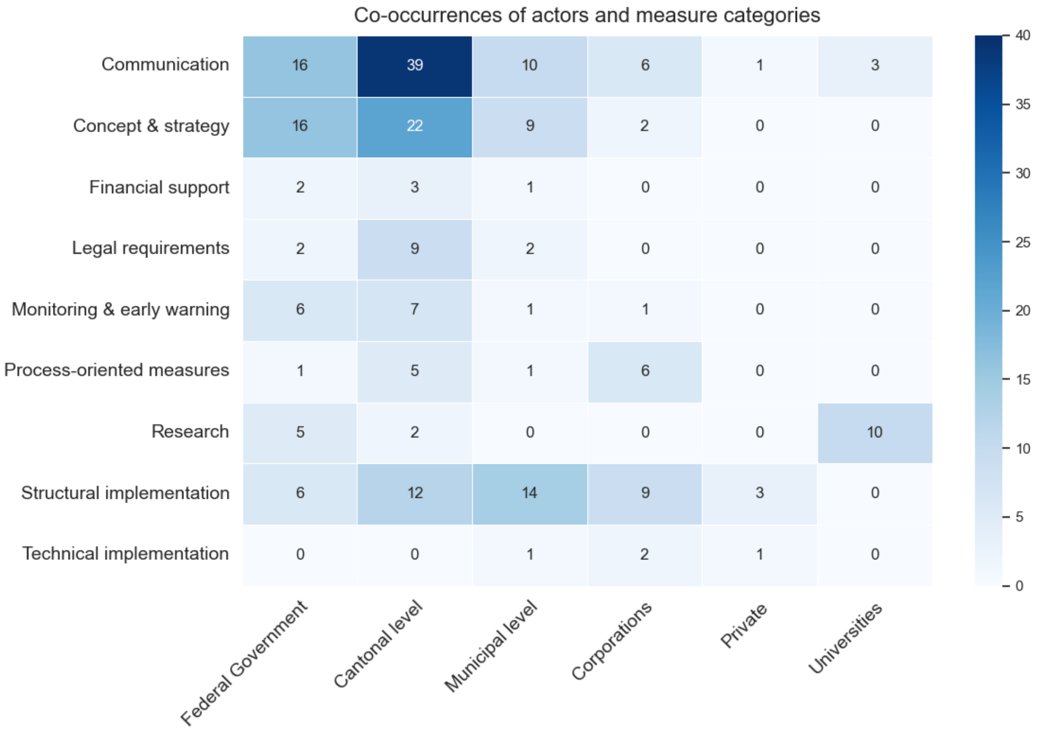


Figure A.1: Word cloud created from the most mentioned one or two word expressions of the 105 unique measure titles.

Figure A.2: Word cloud created from the most mentioned one or two word expressions of the 236 measure descriptions.



Co-occurrences of actors and measure categories

	Federal Government	Cantonal level	Municipal level	Corporations	Private	Universities
Communication	16	39	10	6	1	3
Concept & strategy	16	22	9	2	0	0
Financial support	2	3	1	0	0	0
Legal requirements	2	9	2	0	0	0
Monitoring & early warning	6	7	1	1	0	0
Process-oriented measures	1	5	1	6	0	0
Research	5	2	0	0	0	10
Structural implementation	6	12	14	9	3	0
Technical implementation	0	0	1	2	1	0

Figure A.3: Co-occurrences of measure by the Actors and Measure Category. The co-occurrences show the number of measures in each combination.

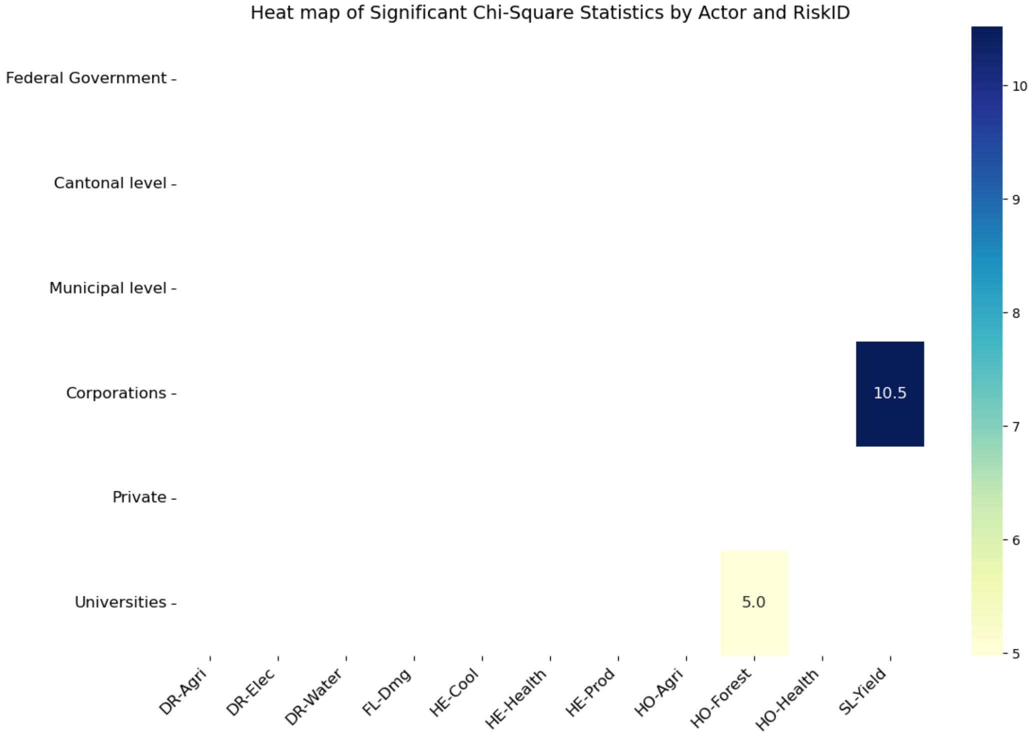


Figure A.4: Chi-square statistic of correlation for the RiskIDs and Actors showing only the significant combinations with p-value ≤ 0.5. Higher Chi-square values indicate a significant association.

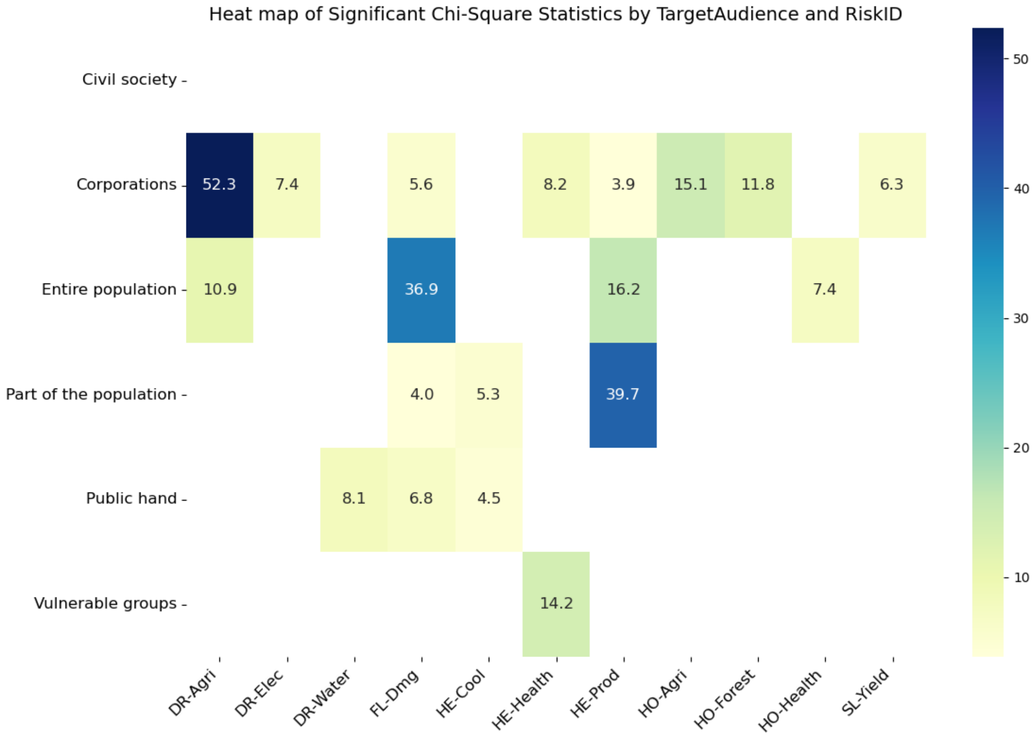


Figure A.5: Chi-square statistic of correlation for the RiskIDs and Target audiences showing only the significant combinations with p-value ≤ 0.5. Higher Chi-square values indicate a significant association.

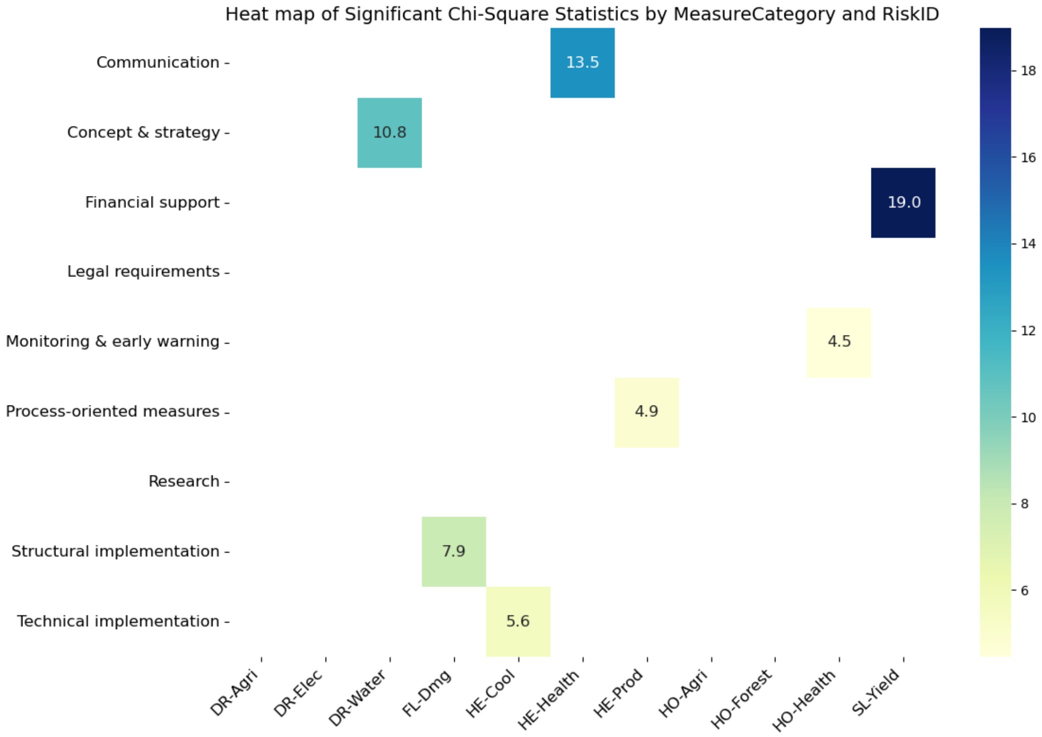


Figure A.6: Chi-square statistic of correlation for the RiskIDs and Measure categories showing only the significant combinations with p-value ≤ 0.5. Higher Chi-square values indicate a significant association.

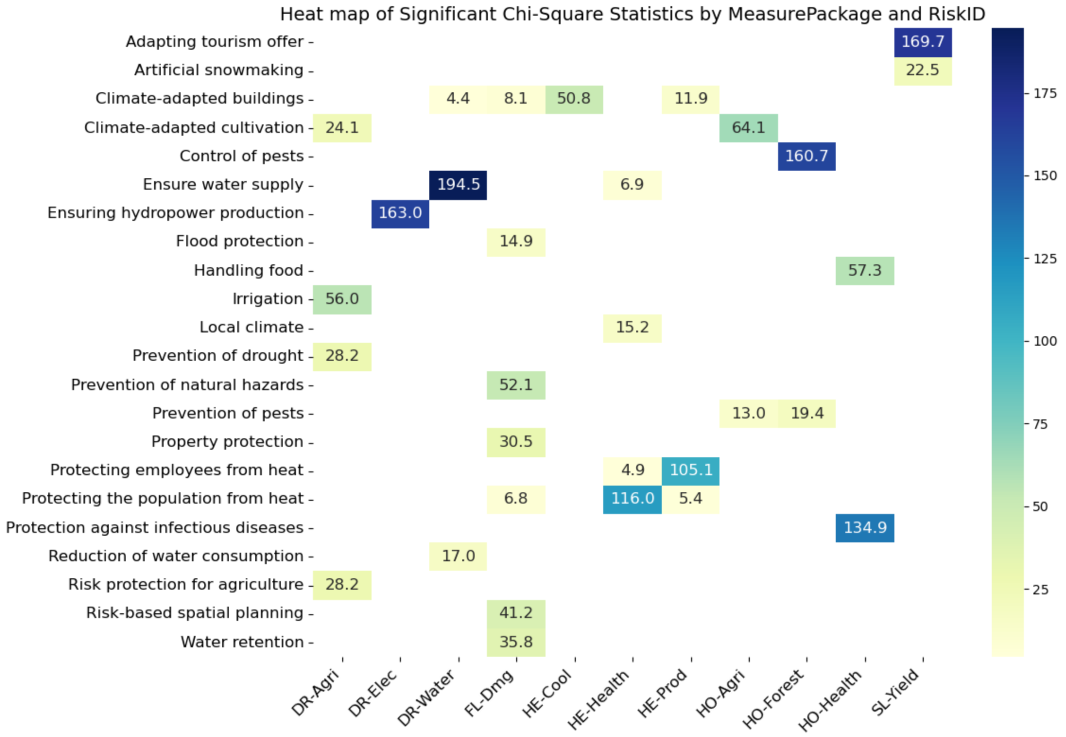
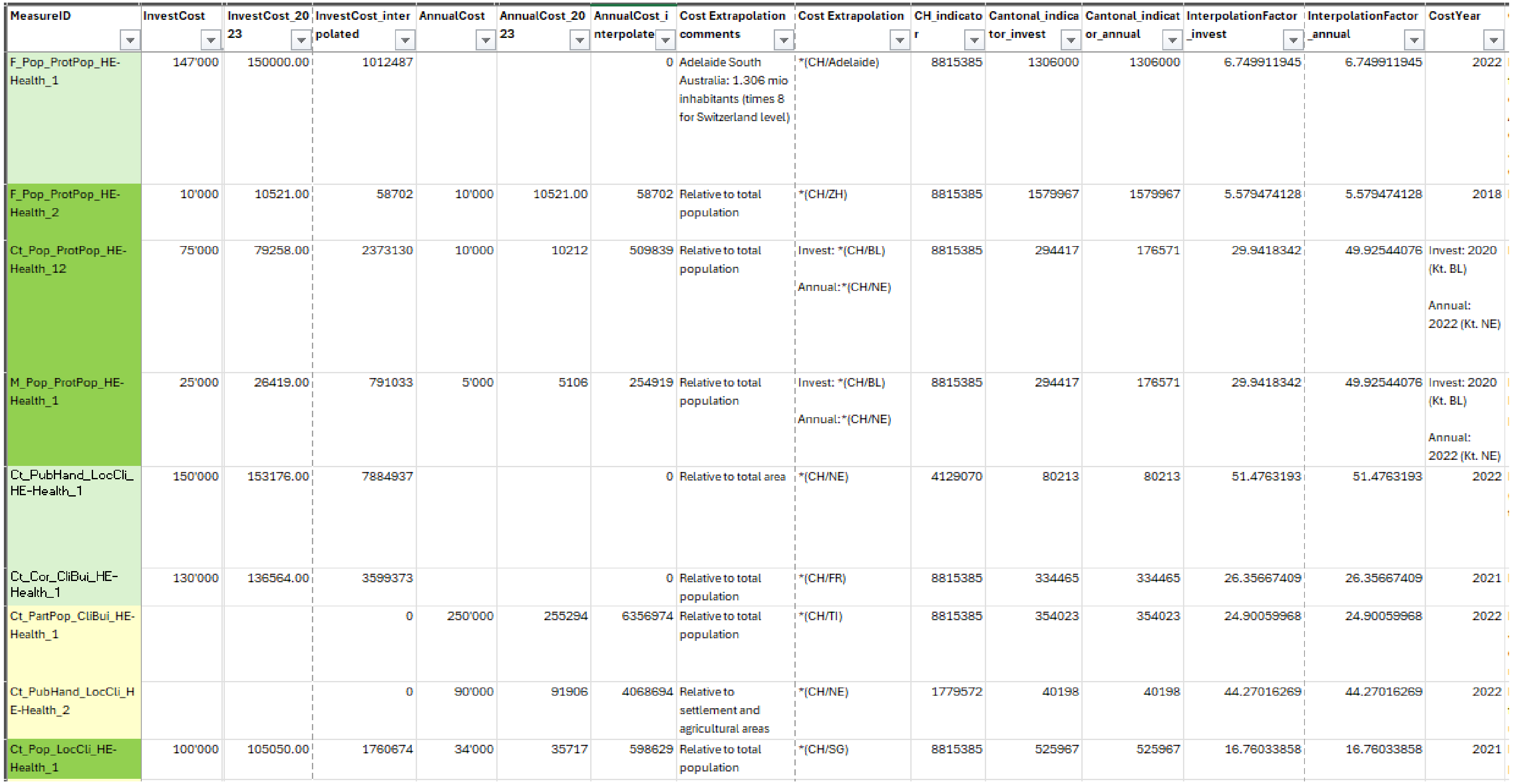


Figure A.7: Chi-square statistic of correlation for the RiskIDs and Measure packages showing only the significant combinations with p-value ≤ 0.5. Higher Chi-square values indicate significant association.



MeasureID	InvestCost	InvestCost_2023	InvestCost_interpolated	AnnualCost	AnnualCost_2023	AnnualCost_interpolated	Cost Extrapolation comments	Cost Extrapolation	CH_indicator	Cantonal_indicator_invest	Cantonal_indicator_annual	InterpolationFactor_invest	InterpolationFactor_annual	CostYear
F_Pop_ProtPop_HE-Health_1	147'000	150000.00	1012487			0	Adelaide South Australia: 1.306 mio inhabitants (times 8 for Switzerland level)	*(CH/Adelaide)	8815385	1306000	1306000	6.749911945	6.749911945	2022
F_Pop_ProtPop_HE-Health_2	10'000	10521.00	58702	10'000	10521.00	58702	Relative to total population	*(CH/ZH)	8815385	1579967	1579967	5.579474128	5.579474128	2018
Ct_Pop_ProtPop_HE-Health_12	75'000	79258.00	2373130	10'000	10212	509839	Relative to total population	Invest: *(CH/BL) Annual:*(CH/NE)	8815385	294417	176571	29.9418342	49.92544076	Invest: 2020 (Kt. BL) Annual: 2022 (Kt. NE)
M_Pop_ProtPop_HE-Health_1	25'000	26419.00	791033	5'000	5106	254919	Relative to total population	Invest: *(CH/BL) Annual:*(CH/NE)	8815385	294417	176571	29.9418342	49.92544076	Invest: 2020 (Kt. BL) Annual: 2022 (Kt. NE)
Ct_PubHand_LocCli_HE-Health_1	150'000	153176.00	7884937			0	Relative to total area	*(CH/NE)	4129070	80213	80213	51.4763193	51.4763193	2022
Ct_Cor_CliBui_HE-Health_1	130'000	136564.00	3599373			0	Relative to total population	*(CH/FR)	8815385	334465	334465	26.35667409	26.35667409	2021
Ct_PartPop_CliBui_HE-Health_1			0	250'000	255294	6356974	Relative to total population	*(CH/TI)	8815385	354023	354023	24.90059968	24.90059968	2022
Ct_PubHand_LocCli_HE-Health_2			0	90'000	91906	4068694	Relative to settlement and agricultural areas	*(CH/NE)	1779572	40198	40198	44.27016269	44.27016269	2022
Ct_Pop_LocCli_HE-Health_1	100'000	105050.00	1760674	34'000	35717	598629	Relative to total population	*(CH/SG)	8815385	525967	525967	16.76033858	16.76033858	2021

Figure A.8: A section of the cost assessment database to showcase the calculations of the interpolation.

Table A.2: Measures which are in the cost assessment database but were not used for the figures of the costs as they all act on the cooling of buildings and only one will be used for each individual building.

MeasureID	**RiskID**	**Actor**	**Measure**	**InvestCost interpolated**	**AnnualCost interpolated**
P_Pop_CliBui_HE-Health_2	HE-Health	Private	Summer thermal protection (buildings)	24375576143	23128098
Cor_PartPop_CliBui_HE-Cool_1	HE-Cool	Corporations	Installation of cooling systems in buildings	1605000000	180562500
Cor_PartPop_CliBui_HE-Prod_1	HE-Prod	Corporations	Installation of cooling systems in buildings	963000000	3210000

Table A.3: Total cost without and with the three removed measures for the "installation of cooling systems" and "summer thermal protection".

Without the 3 Measures	**Amount (CHF)**	**With the 3 Measures**	**Amount (CHF)**
Total Investment Costs	9’289’611’542	Total Investment Costs	36’233’187’684
Total Annual Costs	137’322’111	Total Annual Costs	344’222’709

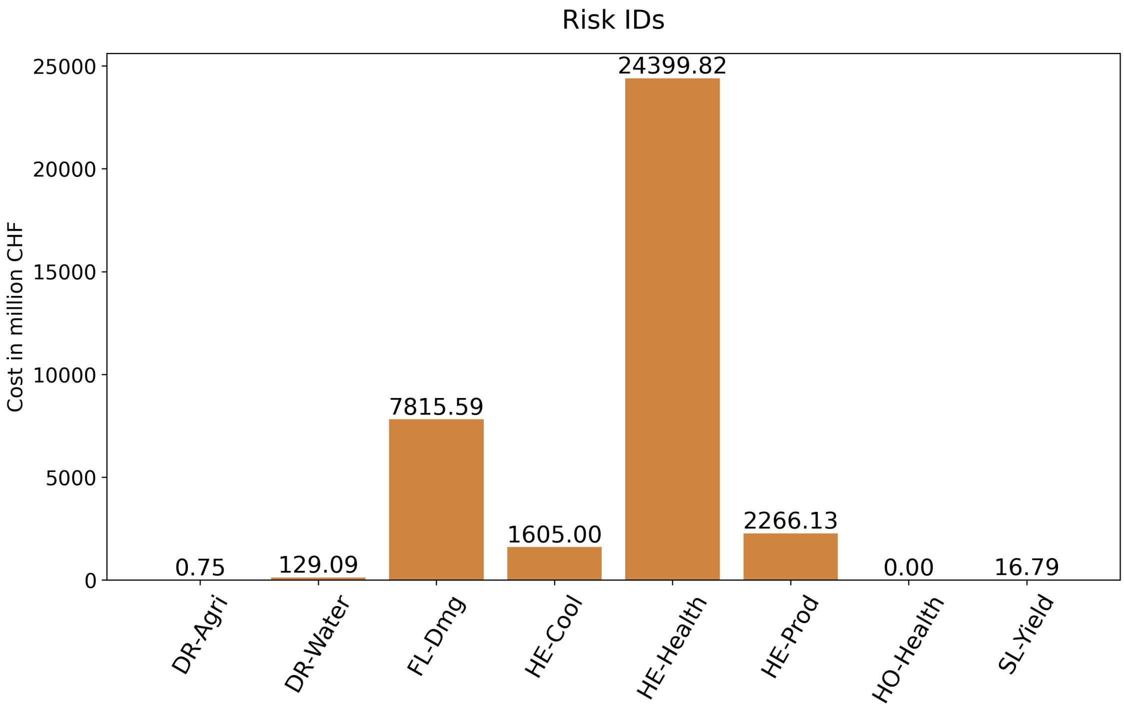


Figure A.9: Investment Cost by Risk IDs

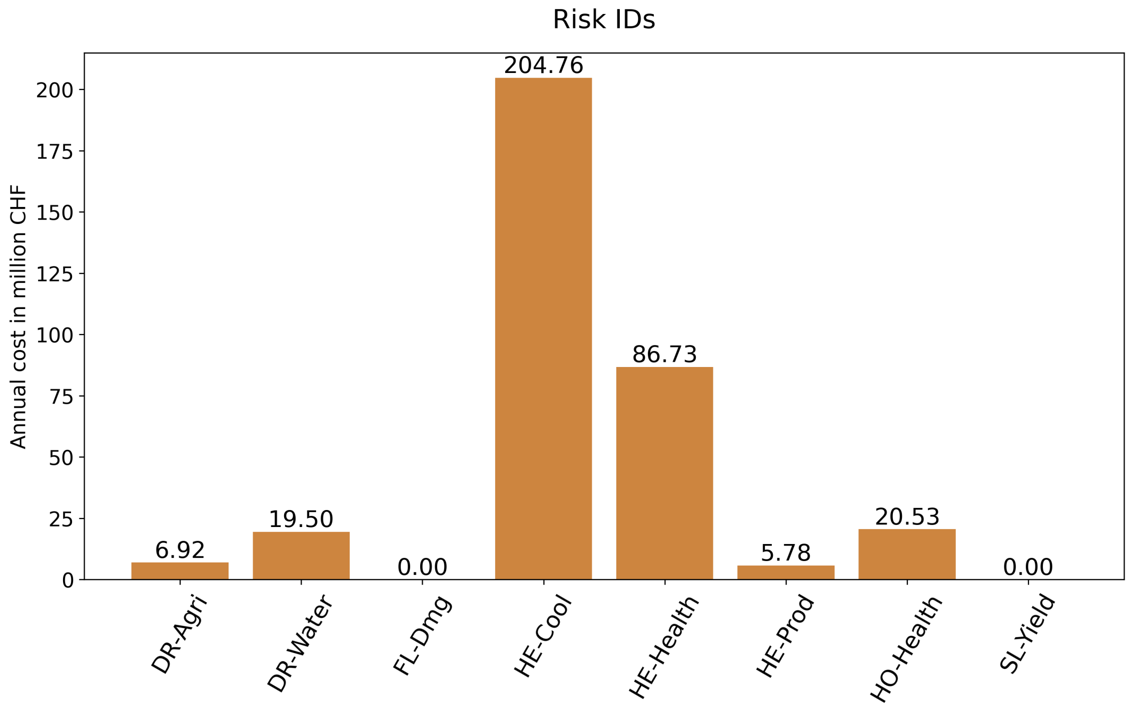


Figure A.10: Annual Cost by Risk IDs

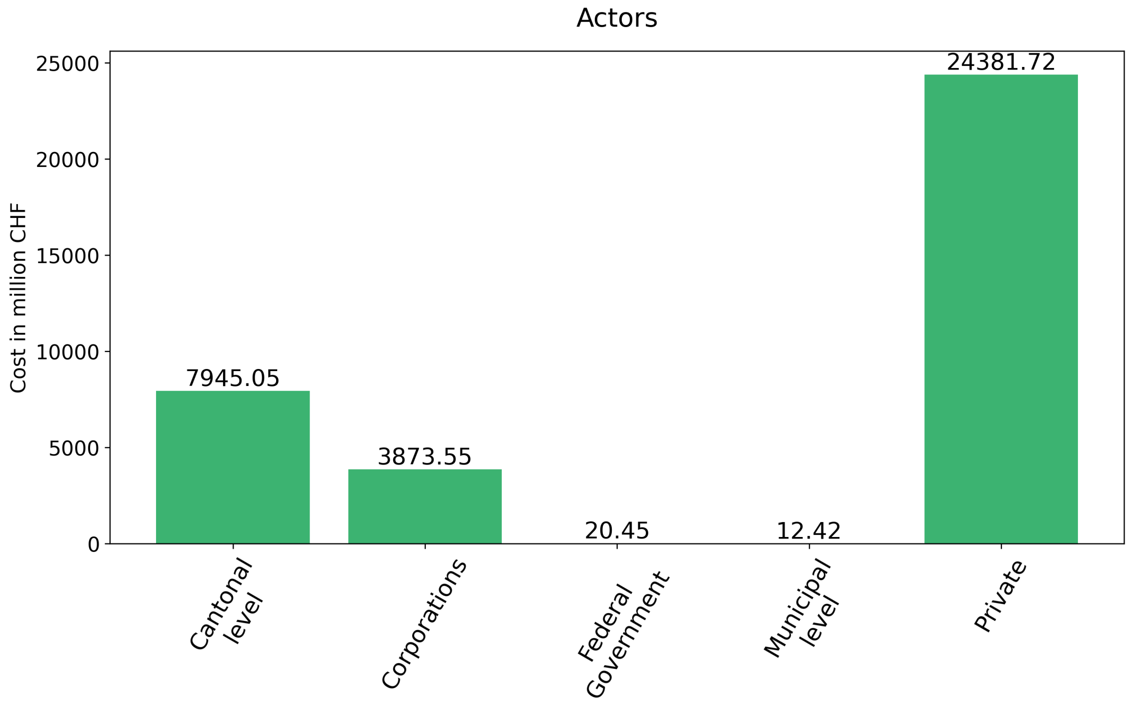


Figure A.11: Investment Cost by Actors

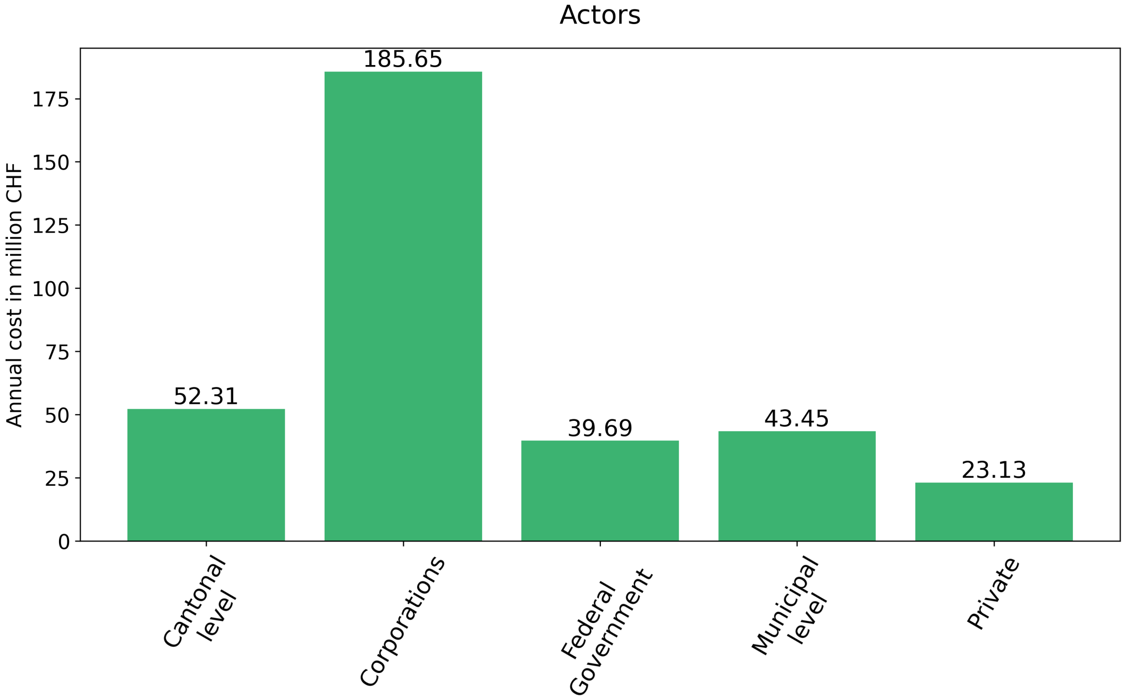


Figure A.12: Annual Cost by Actors

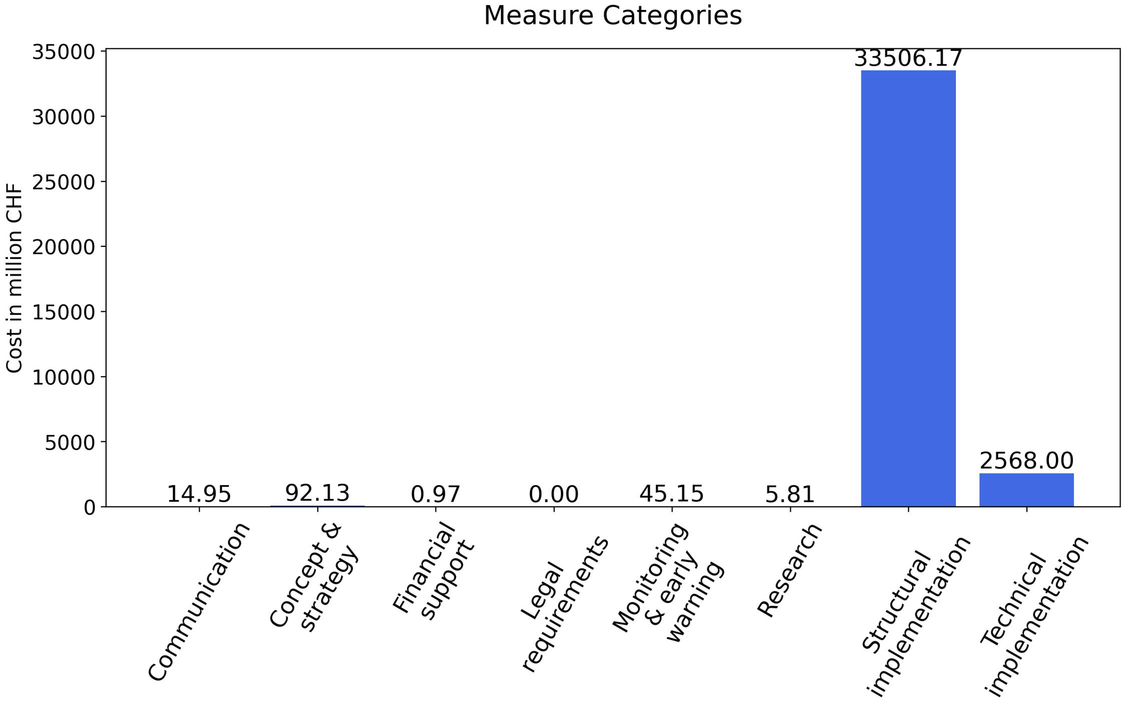


Figure A.13: Investment Cost by Measure Categories

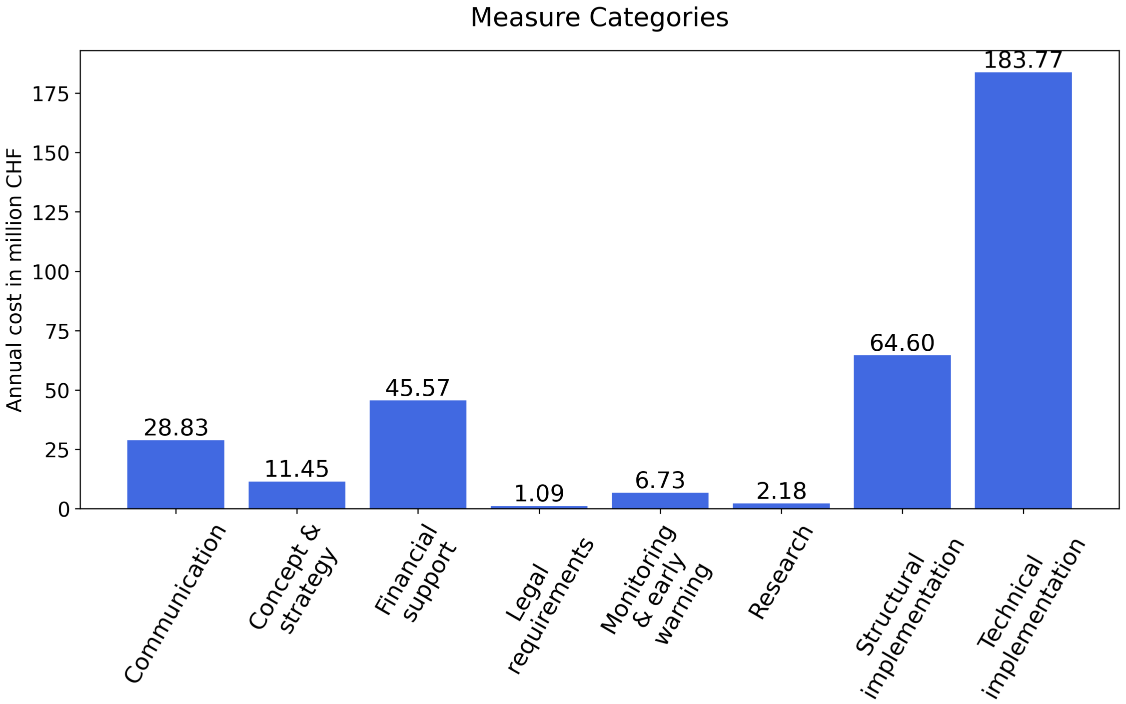


Figure A.14: Annual Cost by Measure Categories

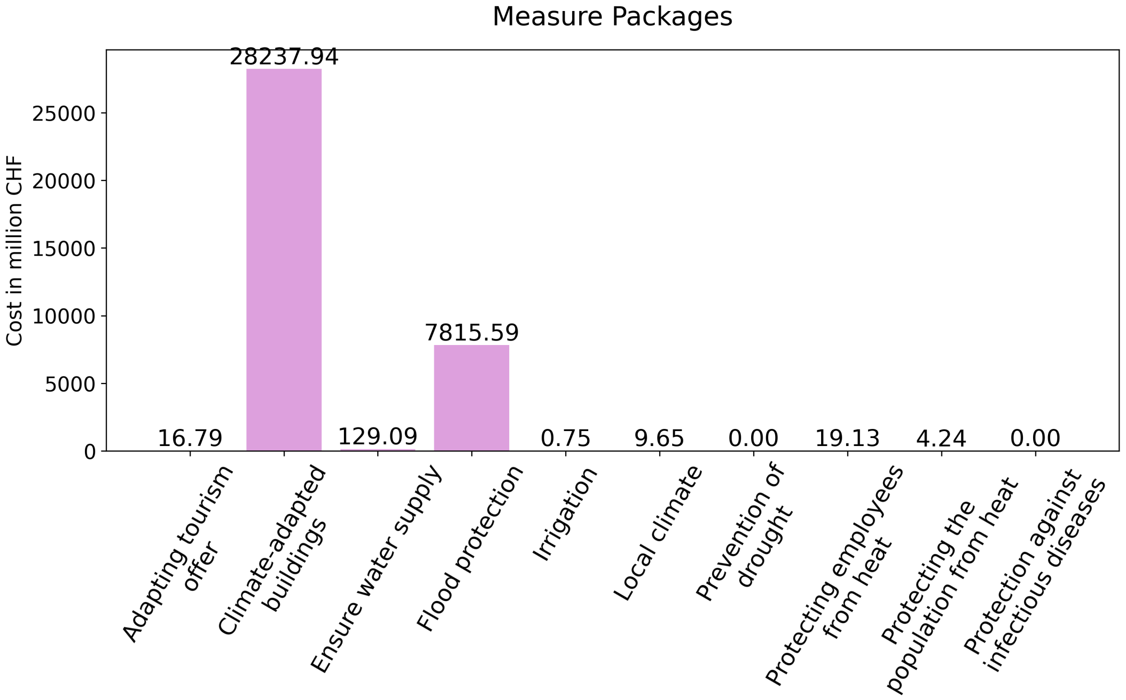


Figure A.15: Investment Cost by Measure Packages

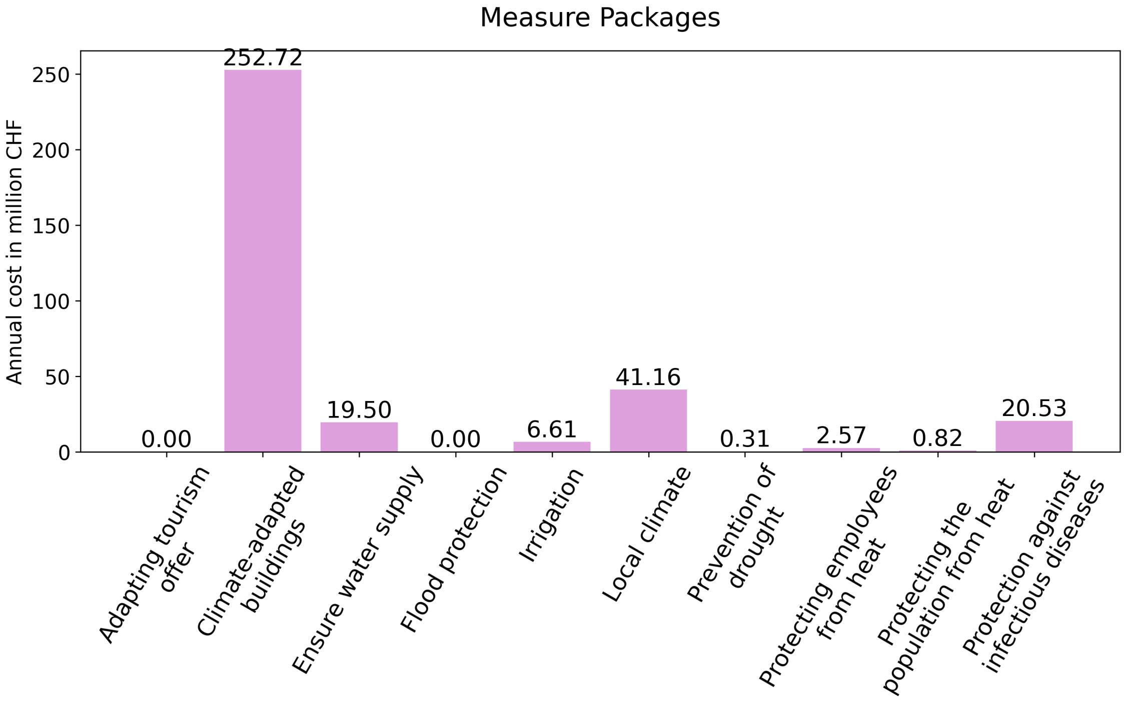


Figure A.16: Annual Cost by Measure Packages

Personal Declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Severin Weber
Winterthur, 27.08.2024