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Master Thesis

Indicators of local climate change impacts and local adaptation strategies of alpine communities in Eastern Tyrol, Austria

Submitted by

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Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

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Kurzfassung

Fuchs, Anna. 2021. Indikatoren für lokale Klimawandelauswirkungen und lokale Anpassungsstrategien in alpinen Gemeinden in Osttirol, Österreich, Masterarbeit an der Universität für Bodenkultur Wien

Der anthropogene Klimawandel ist ein globales Phänomen, dessen Auswirkungen und Anpassungsmöglichkeiten lokal sehr verschieden ausfallen. Ungeachtet dessen finden kleinräumige Untersuchungen, die ortsspezifische sozioökonomische, politische und kulturelle Besonderheiten beachten, in der naturwissenschaftlich dominierten Klimawandelforschung nur selten Berücksichtigung. Lokales ökologisches Erfahrungswissen kann einen Einblick in das Ausmaß der Klimawandelauswirkungen auf lokaler Ebene geben und zu sinnvollen Klimawandelanpassungsmaßnahmen anregen. Daher wurden in dieser Studie die Wahrnehmung von und die Reaktionen auf Klimawandelauswirkungen der lokalen Bevölkerung untersucht. Zu diesem Zweck wurden qualitative Interviews und online Fokusgruppendiskussionen in drei Gemeinden in Osttirol in den österreichischen Alpen durchgeführt. Die befragte lokale Bevölkerung beobachtete eine Vielzahl an Umweltveränderungen, von denen der Großteil (72%) auf den Klimawandel und 28% auf eine Kombination von klimawandel- und nicht klimawandelbedingten Auslösern (z.B. Landnutzungsaufgabe) zurückgeführt wurden. Der Großteil (41%) dieser beobachteten Klimawandelindikatoren beschreibt Veränderungen in Wetter und Klima, je 21,5% betreffen Veränderungen in physikalischen und biologischen Prozessen, und 16% zeichnen sich in land- und forstwirtschaftlichen Systemen ab. Die meisten bisher umgesetzten Anpassungsmaßnahmen an beobachtete Klimawandelauswirkungen betreffen zeitliche Verschiebungen in der Graslandbewirtschaftung, den zunehmenden Einsatz von Bewässerung, sowie den verbesserten Schutz vor Naturgefahren. Trotz einer Vielzahl von Ideen für lokale Anpassungsmaßnahmen, wird deren Umsetzung durch verschiedene Barrieren erschwert. Diese resultieren u.a. aus persönlichen Einstellungen zum Klimawandel (z.B. geringes Betroffenheitsgefühl) und aus grundlegenden sozioökonomischen Veränderungen, wie des Strukturwandels in der Landwirtschaft und der Abwanderung von Arbeitskräften. Dieser Einblick in die Bedenken und Bedürfnisse der lokalen Bevölkerung bieten eine Grundlage für die Entwicklung und Umsetzung nachhaltiger Anpassungsmaßnahmen, sowie eine Chance identifizierte Barrieren zu überwinden.

Abstract

Fuchs, Anna. 2021. Indicators of local climate change impacts and local adaptation strategies of alpine communities in Eastern Tyrol, Austria, Master thesis at the University of Natural Resources and Life Sciences Vienna (Austria)

Although anthropogenic climate change is a global phenomenon, climate change impacts (CCI), vulnerability and adaptive capacity vary from place to place. Yet, small-scale investigations, which are considering place-specific socio-economic, and cultural-political characteristics, are seldomly reflected in climate change research. Local ecological knowledge can provide insights into the extent of CCI on a local scale and inspire meaningful adaptation. This study explores local people's perceptions of and responses to CCI by conducting semi-structured interviews and online focus group discussions in three natural resource dependent communities in Eastern Tyrol, in the Austrian Alps. Local people observed a variety of environmental changes, of which the majority (72%) was attributed to climate change and 28% to a combination of climate change and non-climate change-related drivers, like land-use abandonment. The majority (41%) of the observed climate change indicators described changes in weather and climate, 21,5% changes each were reported on physical and biological processes and 16% in agricultural and forestry systems. Most implemented adaptations to observed CCI concerned temporal shifts in grassland management, increased application of irrigation and greater protection from natural hazards. Despite a multitude of ideas for local adaptation measures, their implementation is hampered by various barriers, which mainly res ult from personal attitudes towards climate change (e.g. lack of concern) and

fundamental socio-economic changes, such as structural change in agriculture and labour migration. An insight in the local populations' concerns and needs provides a basis for developing and implementing sustainable adaption measures, as well as a chance to overcome identified barriers.

Content

1. Introduction

Anthropogenic emissions of greenhouse gases are the highest in history, driving global warming and, since 1950, other changes which have never been seen before over decades to millennia (IPCC 2014). Climate change has already caused serious direct and indirect effects on the climate itself, as well as on biophysical and socio-economic systems. Certain populations and regions experience climate change more severely than others (IPCC 2014). This is particularly true for people who live/work in direct dependence of nature (Green and Raygorodetsky 2010). Mountain areas are regions which are particularly affected by climate change. A wide range of climate change impacts in mountain areas worldwide have already been documented (IPCC 2014). One of them are the European Alps, which show a general increase in temperature and a northward shift of the Mediterranean climate zone. The highly climate sensitive ecosystems of the Alps are already impacted by marginal shifts in climatic variables (Veit 2002; Beniston 2006). Drivers of climate change impacts are documented and predicted in physical, biological as well as socio-economic systems all around the European Alps (Gobiet et al. 2014; APCC 2014).

Although climate change is a global phenomenon, climate change impacts, vulnerability, adaptive capacity and resilience vary from place to place. In other words, their variation is related to the diversity of local conditions in different places. To understand climate change impacts in their full extent and to promote and/or develop meaningful adaptation strategies, the local level needs to be examined too (Wilbanks and Kates 1999). Local ecosystem knowledge is a useful source of information for understanding the effects of climate change and the response to it from the perspective of the local population (Berkes 2009).

Local observation of weather, climate and environment by the local population allows local indicators of climate change impacts to be documented (Reyes-García et al. 2016). Such indicators make it possible to compare different local impacts of climate change on a regional, national or even global scale and to put a local perspective on climate change more into the centre of scientific and political attention. However, this lacks a large number of local case studies in the different climate zones of the world, which follow a social and natural science-based and uniform methodology in order to achieve comparable results (Reyes-García et al. 2019).

With regard to already occurring and predicted changes attributed to anthropogenic climate change, the development and implementation of climate change adaptation measures is gaining importance (Füssel 2007). Here, too, a local approach is essential, since the extent to which people are affected by climate change, their perceptions and their needs are socio-culturally shaped and therefore vary from place to place (Agrawal and Perrin 2009; Byg and Salick 2009). Furthermore, LEK is based on the continuous adaptation of societies to changing environmental conditions and can therefore provide information about so to speak “successfully tested” adaptation strategies and environmental management approaches that strengthen the adaptability and resilience of systems (Berkes et al. 2000). Despite this potential, the experience and knowledge of the local population is rarely integrated into the development of and decisions relating to climate change adaptation (Nelson et al. 2009; Eriksen et al. 2011).

Little research has been done in Europe on local perceptions of climate change (Savo et al. 2016). But this is not because Europe is unaffected by climate change. On the contrary, in the European Alps, for example, the effects of climate change are intensively researched and have been documented, especially by natural science-based studies (Gobiet et al. 2014). The observations and experience of people working in close-to-nature domains and in climate-sensitive areas in the Alpine region could provide additionally insights into how the local population itself perceives climate change, how it affects their life and work and which further changes result from it.

The objective of this master thesis is to gain a better understanding of local people's perception of environmental and climate change and their adaptation to these changes in the context of the European Alps, using a social science approach. More specifically, the case study in three mountain communities in Eastern Tyrol, Austria, aims to

a. assess the historical background and socio-economic context of the local communities.

b. identify local observations of climatic and environmental change impacts and their respective drivers.

c. identify local adaptation measures to climate change impacts.

Based on this, the following research questions were formulated:

1. Which climatic and environmental changes are being observed by the local population?

2. What drivers does the local population attribute to the observed changes?

3. Which adaptation measures are being applied by the local population in response to the impacts of climate change?

2. Literature review

2.1. Impacts of anthropogenic climate change

2.1.1. Climate change

In the meteorological sense climate represents the average weather conditions for a particular location and over long time periods, ranging from some months up to millions of years (WMO 2015). It describes the mean and the variability of essential climate variables like temperature, precipitation and greenhouse gases (GHG), commonly over time periods of 30 years (WMO 2015). Changes in the mean and/or the variability of the climate variables, that persist for an extended period of several decades or longer, characterizes what is called “climate change” (IPCC 2014). These long-term changes can be caused by natural internal processes or external forces, which include persistent human induced changes (a) in the composition of the atmosphere and (b) in land use (IPCC 2014). The term ‘anthropogenic climate change’ refers to the human induced changes in Earth’s climate, while ‘natural climate change’ describes the natural climate variability which has and will always be occurring (NASA GISS 2008).

2.1.2. Climate change impacts

Anthropogenic climate change, caused throughout the last century, has and is predicted to have strong impacts on natural and human systems all around the terrestrial as well as the aquatic world (IPCC 2014). In the context of climate research, “impacts” describe the effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure resulting from climate change and extreme weather and climate events. Already observed impacts can inform about how sensitive natural and human systems are to future climate change. (IPCC 2014) There is strong scientific evidence of different climate change impacts on physical (e.g. cryosphere, hydrology) and biological systems (e.g. terrestrial and aquatic flora and fauna) (Rosenzweig and Neofotis 2013). However, there is fewer evidence of impacts on the human system (e.g. livelihoods, health, food production) clearly linked to climate change, as they are additionally influenced by the different local socio and economic backgrounds, which are, on a global scale, very heterogenous (IPCC 2014).

Regions predominantly inhabited by low-income populations and already marginalised communities are at higher risk of being impacted by future climate change (IPCC 2014). Among others, insecurity in food production and reduction in means of subsistence and income in rural areas, as well as degradation of ecosystems, losses of biodiversity, ecosystem functions, goods and services are predicted to be consequences of climate change (IPCC 2014). Although having marginally contributed to incite anthropogenic climate change (Alexander et al. 2011), peoples and communities who are directly dependent of natural resources for their income and whose cultural identity is tied to the land are and will be strongly affected by these consequences (Green and Raygorodetsky 2010; Savo et al. 2016). In many cases the vulnerability of such communities to climate change impacts is caused by long lasting external influences, which can be described as “a combination of political forces and social structures that erode their resource base and their traditional institutions” (Nakashima et al. 2012).

Regions of higher latitude and elevation are projected to be stronger effected by climate change (IPCC 2014; Gobiet et al. 2014). Considering that mountain regions occupy approx. 27% of Earth’s surface, are inhabited by approx. 1,1 billion people and provide goods, services and freshwater to approx. half of humanity and are centre of biodiversity (UNCED 1992), shows how far-reaching the consequences of climate change in mountain areas could be and emphasizes the need to investigate climate change impacts in these areas. Conveniently mountain environments are optimal regions to detect climate change and assess climate change impacts (Rogora et al. 2018), as climate, ecological and hydrological conditions change rapidly with altitude over relatively short distances (Whiteman 2000 in Rogora et al. 2018).

2.1.3. Climate change impacts in the European Alps

The European Alps are characterized by diverse ecosystems. Their glaciers provide an important water resource, as well as a touristic and cultural asset. Many of the habitable regions of the Alps are densely populated and shaped by tourism, transportation, hydropower. Agricultural as well as industrial activities (Brönnimann et al. 2014).

In Europe, the Alps are particularly affected by climate change, as they form the border between the Mediterranean and the European temperate climate zone. Beside a general warming trend, the region thus is also affected by a northward shift of the Mediterranean climate zone. The Alps complex topography further intensifies their sensitivity for climatic change (Hohenwallner et al. 2015). Already small changes in the climate variable temperature and/or precipitation become evident through shifts in spatial boundaries (e.g. treeline, snowline) (Veit 2002) and lead to drastic impacts on terrestrial and freshwater ecosystems and all the associated services they provide for the human population (Hohenwallner et al. 2015). The below mentioned examples shall give some insight in the climatic changes and climate change impacts documented and predicted in the European Alps so far.

In the Alps an overall increase in temperature, changes in seasonal cycles of precipitation, global radiation and humidity, as well as changes in temperature and precipitation extremes are reported for the 21th century. In higher elevations an uncommon warming due to the reduction of snow cover and the intensification of the general snow-albedo feedback is projected, but also in lower elevations temperatures shall rise during summer. Global radiation and relative humidity are expected to change according to the seasonal cycle of precipitation, which is predicted to decrease in summer and increase in winter. Relative humidity is expected to especially decrease in summer. In higher elevations, precipitation might increase in summer, but decrease in winter. Furthermore, the intensity and the frequency of temperature and precipitation extremes is predicted to increase (Gobiet et al. 2014).

Such changes in temperature and precipitation have impacts on the snow cover as well as on the occurrence of floods, droughts and natural hazards. An intensification of precipitation will lead to more frequent and severe flooding in the Alps. The increasing temperatures will result in more severe drought regimes, but also cause a large decrease in alpine snow amount and duration below elevations of 1500-2000 m (Gobiet et al. 2014). Higher temperature and global radiation together with reduced snow fall and albedo lead to a reduction in glaciers. Beside glaciers, permafrost is also decreasing (APCC 2014). The increased glacial melting and thawing of permafrost have substantial hydrological and geophysical consequences, leading to a higher frequency of natural hazards like rockfalls, landslides or more intense debris flows (Gobiet et al. 2014).

Impacts of climate change on biological systems in the European Alps are characterized by a loss of biodiversity in terrestrial and aquatic habitats as well as by the partial degradation of these habitats (Körner 2004). Increasing temperature force many species to migrate to higher elevations (e.g. Pauli et al. 2012, Staffler et al. 2011). Another danger for biodiversity resulting from climate change, is the amplified spreading of invasive species (Richter et al. 2013; Walther et al. 2009). Also, pests and diseases are increasing in frequency and intensity (e.g. bark beetles) (e.g. Steyrer and Krehan 2011) in part due to warmer winters, which fail to supress the responsible organisms (Gobiet et al. 2014). Lengthened vegetation periods (e.g. Eitzinger et al. 2009), changes in the phenology of different plant species (e.g. Perroud and Bader 2013) and increased drought stress in mountain forests (e.g. Dobbertin 2005; Jolly et al. 2005) are further changes documented in the biosphere.

Climatic changes and the consequent changes in biophysical systems are affecting different socio-economic sectors in the European Alps. For example, the increasingly warm winters and the reduced snow cover, together with associated changes in the timing and amount of surface runoff, can impact tourism, agricultural production and the water- and energy sector (e.g. hydropower) (Hohenwallner et al. 2015). For several mountain communities this could for instance signify a reduced income obtained from winter tourism (Steiger and Trawöger

2011). Extreme summer temperatures and drought can trigger negative impacts on human health and agroecosystems, while more intense precipitation events and floods can cause serious damage to life and infrastructure (Gobiet et al. 2014).

2.2. Adaptation to climate change impacts

As the increasing occurrence and severity of climate change impacts becomes undeniable, evermore attention is directed to ways on how to respond to the present and future climatic changes. Two of the most commonly considered responses to climate change and climate variability are 'mitigation' and 'adaptation' (Füssel 2007). In this context, mitigation includes all human interventions which reduce or stabilize greenhouse gas emissions or levels, in order to mitigate changes in the climate (IPCC 2014; Smit et al. 2000). Both in climate change science and politics, mitigation has traditionally received more attention than adaptation due to several reasons. In contrast to adaptation, mitigation can for example (a) target climate change impacts in all climate-sensitive systems globally, (b) is certainly beneficial in the long run, as it reduces the original source of climate change problems, (c) holds the responsible climate polluters accountable (polluters-pay principle) and (d) is easier to monitor by measuring greenhouse gas emissions (Füssel 2007).

Yet, anthropogenic greenhouse gas emissions already altered climate conditions and extremes – with substantial impacts on many natural and social systems – and global warming is predicted to increase at even faster rates, irrespectively of the emission scenarios. Therefore, it is recognized that mitigation alone is not sufficient to face climate change and adaptation is increasingly considered an essential complement to mitigation (Füssel 2007). As Agrawal and Perrin put it more drastically: "*After all, the only alternative to adaptation is extinction unless the world strictly and immediately limits its future emissions, an outcome surely in doubt given the record of the past decade*" (Agrawal and Perrin 2009, p. 350). An important strength of adaptation in comparison to mitigation is, that it can take place at different scales – from local to global – targeting the specific climate change impacts, adaptation needs and capacities of a group of actors (Adger et al. 2005).

2.2.1. Climate change adaptation

What, however, is climate change adaptation exactly? The concept of adaptation is used in many disciplines (e.g. ecology, social sciences), which have their own specific definitions for it (Smit et al. 2000). Also, in climate change literature a variety of definitions have been suggested. A general description, which is part of many of those definitions, refers to adaptation in the climate change context as "*an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts." (Smit et al. 2000, p. 225)* However, to define what adaption is in a specific context more precisely, it can be expedient to find the answers to the three questions (1) "adaptation to what?", (2) "who or what adapts" and (3) "how does adaptation occur". With these questions (a) the climate-related stimulus, (b) the system of interest and (c) the processes and forms of adaption can be specified (table 1). All three elements are interdependent – for example, some systems are more adaptable to a given climate stimulus than others, or the adaptation process might modify the impacted system – so that its sensitivity to climate stimuli is altered. Also, the system concerned can be influenced by not climate related external forces and conditions (e.g. economic and institutional arrangements) (Smit et al. 2000).

Table 1: Extent of climate change adaptation. Based on APCC (2014, p. 732).

Main questions	Dimensions	Adaptation fields					
Adaptation to what?	Climate stimuli	Past climatic changes	Contemporary climate variations	Future climatic changes			
	Impacts	Direct impacts	Indirect impacts				
Who or what adapts?	Actors (selection)	Individual	Enterprise	NGO	government		
	Sectors (selection)	Water	Agriculture	Health	Tourism	Industry	
	Decision levels (selection)	Local	Regional	National	European	International	Multi-level
How does adaptation occur?	Temporal scale	Short-term	Medium-term	Long-term			
	Purpose and timing	Autonomous/ reactive	Planned/ proactive				
	Form (selection)	Informative	Juridical	Technological	Mixed		
	Approach	Top-down	Top-down and bottom-up	Bottom-up			

Adaptation to what: This question targets the phenomena to which adaptation is made, which, in this context, are climate-related stimuli. Yet, it is necessary to specify these stimuli according to the respective climate characteristics (e.g. temperature, precipitation) and their connection to the system which adapts. Climate stimuli can vary in time (e.g. long-term trends to isolated extreme events) and scale (e.g. stimulus experienced locally or over a large area). The effects of these climate stimuli can be either direct or indirect, via environmental, social or economic manifestations and include both risks and opportunities. Beside climatic stimuli, also other non-climatic conditions influence the sensitivity of systems and thereby the nature of their adaptive responses. The system's adaptation to theses stimuli can lead in diverging directions: ranging from an improvement to an aggravation of the situation. (Smit et al. 2000)

Who or what adapts: An adaptation is an adjustment in 'something'. This 'something', is the system that needs to be closely defined according to its spatial scale (e.g. individual or community; region or nation or globe), its nature or scope (e.g. adaptation in a species, an ecosystem, an economic sector, a social structure or a political entity) and its temporal scale (e.g. instantaneous properties or over years or decades). Defining the boundaries of a system is important, because adaptions can vary essentially from scale to scale. In an agricultural context for example, if the system is defined as the farmer's field, the adaptation to a climate stimulus - e.g. drought - could be planting a new hybrid, whereas if the system would be defined as the farm or the regional/national level, the adaptions could be diversification or changes in the number of farms/modifications to a compensation program. As a system both 'who' and 'what' can exert and experience adaptations (e.g. authorities, forest manager (who); coastal zone, forest (what)). (Smit et al. 2000)

Besides defining the boundaries of the system, attention also needs to be payed to the system's characteristics. They influence whether a system needs to adapt and it's likelihood to adapt. They promote, inhibit, stimulate, dampen or exaggerate the occurrence and nature of adaptations (Smit et al. 2000). Many studies focus on the analysis of these characteristics, because the obtained information is considered necessary to develop suitable adaptation measures (e.g. assessment of climate change vulnerability) (Foden et al. 2019) - which are further used for policy recommendations or to better estimate future impacts of climate change (e.g. impact assessment: calculating residual impacts) (Smit and Wandel 2006). A selection of common characteristics and inherent definitions is displayed in table 2 and figure 1. The characteristics in question are usually divers, originating from different disciplines (e.g. hazard research, conservation), partly overlapping in their meaning. Vulnerability, for instance, constitutes of exposure and sensitivity to climatic risks and the adaptive capacity to deal with those risks (Smit and Wandel 2006; IPCC 2001, p. 388). Adaptive capacity is again closely linked to the concept of resilience, which, among others, describes the ability of a socio-ecological system to respond to external disturbances, stress and change (IPCC 2007, p. 86). A vulnerable social-ecological system might be described as not resilient, thus exhibiting a low adaptive capacity (Nakashima et al. 2012). All of these characteristics are closely related to socio-cultural and political-economic forces and conditions relevant/present in the system of interest. Taking a closer look at these non-climate related conditions can be helpful to better understand why, for example, one community is more vulnerable to climate change than another and how a change in 'external' conditions could help to reduce vulnerability/increase adaptability (Smit et al. 2000).

Table 2: Characteristics of systems dedicated to adaptation due to climate change.

Characteristic	**Definition**	**Source**
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.	IPCC 2007, p. 89
Exposure	Degree of climate stress upon a system	IPCC 2001, p. 373
Sensitivity	Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).	IPCC 2007, p. 86
Adaptive capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences, in relation to climate change (including climate variability and extremes).	IPCC 2014, p. 118, 2001, p. 365
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change. Resilience research focuses on the capacity of social-ecological systems to respond to external disturbances, such as those arising from climate change	IPCC 2007, p. 86, Nakashima et al. 2012

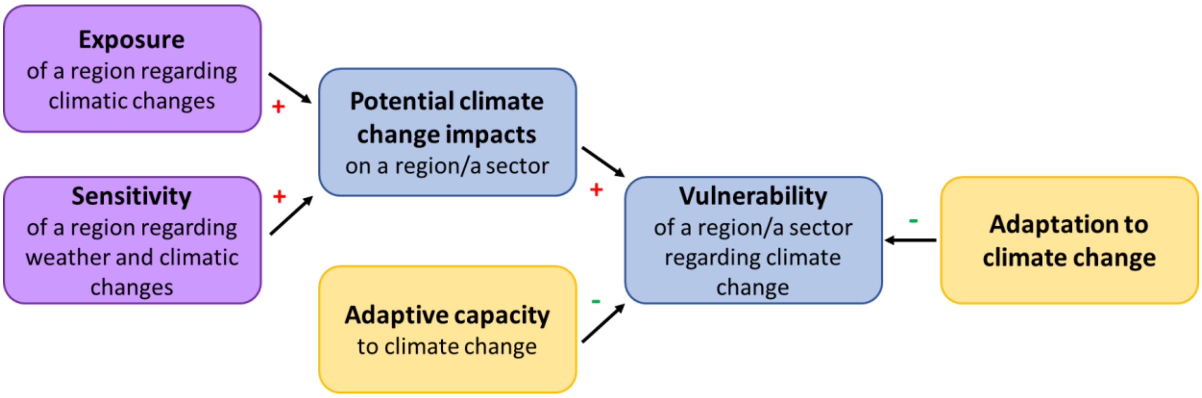

Figure 1: Relation between exposition, sensitivity, vulnerability, adaptive capacity and adaptation in regard to climate change. Arrows indicate whether an increase in the presented characteristic is amplifying (+) or reducing (-) vulnerability regarding climate change impacts (APCC 2014, p. 660)

How does adaptation occur: The term adaptation is used for both a process as well as an outcome/condition resulting from the adaptation process. It can occur via different ways and take many shapes. There are several dimensions of adaptations suggested in literature. For example adaptations can be classified based on their purpose and timing (e.g. autonomous/reactive or planned/proactive adaptation), their temporal scale (e.g. short to long-term), their intent (e.g. decrease vulnerability), their form (e.g. technological, behavioural, financial, institutional or informational) or their approach (e.g. bottom-up). (Smit et al. 2000; APCC 2014; table 1).

Another relevant term concerning the temporal scale of climate change responses is "coping". Agrawal and Perrin (2009) define coping as: "The use of existing resources to achieve various desired goals during and immediately after unusual, abnormal, and adverse conditions of a hazardous event or process." Thornton and Manasfi further explain "*Coping strategies entail immediate measures that may help to survive an unusual decline in resources but may not be sustainable in the long run. In contrast, adaptation strategies tend to spawn new cultural configurations that have evolved in response to changed conditions"* (Thornton and Manasfi 2010, p. 147).

2.2.2. Barriers to climate change adaptation

Although adaptation is recognized as an essential element to respond to climate change, not every adaptation process – be it local or global, autonomous or planned - is successful. Adaption occurs embedded in complex and interlinked socio-ecological systems, which are impacting each other in various ways. Within this complex situations, climate and non-climate-specific events, factors and conditions can negatively influence the process of successful adaption to climate change. To make these events, factors or conditions more tangible and identifiable, Biesbroek et al. (2013) introduces the term 'barrier to adaptation'. Gaining a deeper understanding of adaptation barriers can serve as valuable information for planning and implementing adaption actions and policies.

Building on previous attempts to conceptualize such barriers to adaptation, Biesbroek et al. (2013) define barriers as : "*(1) the actors' subjective interpretations or collective understanding of (2) sequentially or simultaneously operating factors and conditions that (3) emerge from the actor, the governance system, or the system of concern, (4) which the actor values as having a negative influence on the process and reduce the chances of successful outputs, but (5) that are manageable and can be overcome with concerted efforts, or (6) by creating and seizing opportunities."* (Biesbroek et al. 2013, p. 1127) In contrast to barriers, adaptation limits are sometime defined as definite, meaning that they cannot be surpassed without resulting in irreversible loss, and/or radical system shifts, including innovation and novelty (Moser and Ekstrom 2010).

bbSo far, a great number of barriers to adaptation have been reported in literature and different attempts to categorize them have been made (Eisenack et al. 2014; Biesbroek et al. 2013). Yet, it is to note that barriers are highly context dependent, which constrains the development of a consistent framework to assess barriers to climate change adaptation systematically and to compare them across different contexts. Within adaptation barrier research, there is the tendency to investigate ‘which’ barriers are existing, while the questions of ‘how’ or ‘why’ the barriers have emerged are rarely asked (Biesbroek et al. 2013). It is suggested that further research on barriers to adaption shall follow an actor-centred and more systematic approach, focusing on what causes barriers and how they interact and change over time. (Eisenack et al. 2014; Biesbroek et al. 2013)

2.3. Weaknesses of current climate change research

Current climate change research is dominated by natural science-based studies (Overland and Sovacool 2020; Callaghan et al. 2020). Thus, in many cases, the evidence of the effects of climate change is based on weather and climate observation data, combined with climate model data for areas where climate records are unavailable (WMO 2015). As informative as these modelling techniques can be on large spatial and temporal scales, they are not free from uncertainties (Randall et al. 2007; Hawkins and Sutton 2011). Climate models’ reliability decreases at smaller scales, because detailed local climate observations are limited (Randall et al. 2007) and downscaling of global models cannot compensate the lack of place-specific data (Maraun et al. 2010).

Instead of following this top-down research approach from global to local, it is suggested to promote more local case studies which investigate the place specific impacts of climate change in cooperation with affected local communities (Wilbanks and Kates 1999). Moreover, to fully understand human interaction with and response to climate change, it is also necessary to consider their social, economic, political and cultural context (Jasanoff 2010). This demands a stronger inclusion of social sciences in the investigation of climate change impacts (Overland and Sovacool 2020).

2.4. Climate change from a local perspective

The local ecological knowledge of communities who have a long history of interaction with their environment can provide a complementary source for better understanding the impacts of climate change (Berkes 2009). This implies learning from people’s knowledge, practices and beliefs, which they acquired through long-term observations of and constant adaptation to their local environment (Berkes et al. 2000). The thereby developed complex knowledge systems enables them to not only detect the changes in the local weather and climate, but also to perceive their effects on the local environment and possibly to respond to them (Green and Raygorodetsky 2010)

2.4.1. Local ecological knowledge

Besides local ecological knowledge – thereafter LEK –, also the terms “traditional (ecological) knowledge” (TK/TEK) and “indigenous (ecological) knowledge” (IK/IEK) can be frequently found in literature. These terms are often used synonymously, yet some authors differentiate between them depending on the thematic focus (Hernández-Morcillo et al. 2014). Studies interested in the historical development of this knowledge, thus the long-term coevolution and continuity of ecological and cultural systems, often tend to speak of it as traditional (ecological) knowledge (Hernández-Morcillo et al. 2014). In many cases where the term local (ecological) knowledge is used, the regional uniqueness of knowledge, e.g. of a specific ecosystem, landscape or land use system and the associated local communities, is central (Hernández-Morcillo et al. 2014). Indigenous knowledge in turn, is mainly used to indicate that the holders of the investigated traditional/local knowledge are indigenous people, whereas TEK and LEK can also be held by non-indigenous communities (WIPO 2011).

Independent of the name, the concept describes a "cumulative body of knowledge, practices and beliefs" (Berkes 1999, p. 8) that humans/societies developed through the daily interaction with and continuous adaptation to their local environment and which is passed on through cultural transmission from one generation to the next. Such knowledge systems include the understanding of ecological processes and the natural resource management strategies adapted to them (Berkes et al. 2000).

While minding the relevance of locally created knowledge, it is also necessary to consider that in modern times such LEK systems, are not isolated but exposed to many external factors and developments. Nowadays other means of knowledge input exist in addition to cultural transmission (Ingold 2003). Especially in non-indigenous communities, place-bound knowledge originating from local ancestors is often intermixing with popular and scientific knowledge, which is, for example, communicated via the media (Aswani et al. 2018). Also factors like migration or demographic shifts have influential effects on the LEK of people (Albuquerque and Alves 2016). Furthermore, the continuity of LEK is challenged by overarching developments like market integrations, globalization or industrialization (Aswani et al. 2018). Despite the resulting trend of LEK loss due to these aspects, there are still pockets of LEK existing around the world (Aswani et al. 2018). Their persistence highlights that LEK is dynamic, adaptable to changing circumstances and partly also merging with new forms of knowledge, creating hybridized knowledge (Gómez-Baggethun et al. 2013).

As a scientific concept, LEK only became of greater interest in the 1960s. In addition to its significance in disciplines like anthropology and ethnobiology, which investigate indigenous knowledge systems, LEK also gained more importance in the field of ecology in the 1990 (Albuquerque and Alves 2016). In the last 30 years, the contribution of LEK to sustainable resource management (Berkes et al. 2000), to sustaining biodiversity and ecosystems services (Gadgil et al. 1993) and building resilience in socio-ecological systems (Folke 2004; Berkes and Davidson-Hunt 2006; Gómez-Baggethun et al. 2012) has been increasingly recognised in research and in politics. Investigating the use of these and further attributes of LEK especially gained attention in the context of present and future global environmental change and climate change (Vedwan 2006; Salick and Ross 2009; Green and Raygorodetsky 2010; Gómez-Baggethun et al. 2013; Pyhälä et al. 2016).

2.4.2. Local knowledge about climate change

Anthropological research shows that throughout human history, societies - living in close interaction with and exposure to the environment - repeatedly had to deal with climatic and environmental changes. Communities' continued existence depended on the generation of different ways to adapt their practices to these changes (note: also maladaptation and extinction occurred). Doing so, required the ability to first detect and interpret local meteorological phenomena (Barnes et al. 2013). Within the concept of local knowledge, such ethnoclimatology knowledge (Orlove et al. 2002) has only been sparsely documented in the past, but has recently become increasingly important for a more contextualized understanding of and responding to climate change in local communities (Strauss 2018).

Burger-Scheidlin (2007) conceptualizes local knowledge in relation to weather and climate in 5 spheres: (1) through observations of nature and external information (e.g. media) local people can classify and describe weather phenomena. (2) Interpreting these observations can lead to an understanding of how such weather phenomena impact each other and ecosystems. (3) Practical experiences with the nature and dynamics of these weather phenomena leads to specific behaviour of local people, (4) which can potentially also regulate, compensate or amplify weather phenomena. (5) All observations, their conversion in knowledge and resulting actions are influenced by the local believes and worldview. Application and transmission of knowledge and practice are incorporated and shaped by the prevailing social organisation and the local institutional context. Recent local communities are reported to directly observe short to long-term weather and climate variability (Orlove et al. 2002; West et al. 2008) and resulting impacts on the local biophysical systems, their daily practices and their socio-cultural context (Reyes-García et al. 2016; Savo et al. 2016). Therefore, local people's perception of environmental and climatic change, are considered as a valuable source for not only better understanding climatic changes and possible adaptations on a local scale, but also to inform climate change discussions on regional, national and international levels (Leonard et al. 2013; Berkes et al. 2000).

Scientific literature on local knowledge about climate change comprises to a great part of case studies investigating different indigenous or non-indigenous/local knowledge systems around the world. Reoccurring thematic foci are (a) observations of local weather and climate variabilities (e.g. Lefale 2010; Marin 2010; Ogalleh et al. 2012), (b) observed climate change impacts on biophysical and socio-cultural systems (e.g. Azzurro et al. 2011; Byg and Salick 2009; Cochran et al. 2013), (c) local adaptation to climate change (e.g. Pearce et al. 2015; Galappaththi et al. 2019; Gómez-Baggethun et al. 2012), (d) the complementarity of local and scientific climate change knowledge (e.g. Ford et al. 2019; Alexander et al. 2011, Riedlinger and Berkes 2001) and (e) the integration of local knowledge in climate change research and policy debates (e.g. Savaresi 2018, Tengö et al. 2017; Ford et al. 2016).

2.5. Local observations of climate change

2.5.1. What climate change research can learn from local observations

Local observations of climate change and climate change impacts are considered as valuable due to several reasons. Local observations can help to detect climate change induced variations, for example in animal migration patterns and abundance (Azzurro et al. 2011), which can have significant impacts on the local scale, but are not well reflected in current climate model simulations (Savo et al. 2016). Local observations do not need to be a replacement, but can inform in combination with other data sources (e.g. instrumental climate data (Fernández-Llamazares et al. 2017), satellite images (Yager et al. 2019)), thereby strengthening the data basis of global climate change analyses (Savo et al. 2016). Also, local observations can provide data for areas where instrumental data are sparse or not available (Reyes-García et al. 2019).

Observations based on long-term experience in a specific place can also support formal climate science to understand local ecological processes, how they interact and respond to climate change (Savo et al. 2016). Another strength of human observations is that they recognize the interconnection between climatic changes and their social and environmental consequences, which can be very versatile. Local observations can thus provide a more holistic view in addition to instrumental or modelled climate data and help to better understand the social impacts of climatic changes (Savo et al. 2016). Yet it is essential to carefully distinguish social impacts of climate change from other changes impacting society (e.g. land use changes, demography shifts, pollution) (Rosenzweig and Neofotis 2013), as their effects might be perceived as more urgent and threatening by the local population (Barnes et al. 2013).

2.5.2. Shortcomings of research on local observations of climate change

Three literature reviews, two published in 2016 (Reyes-García et al.; Savo et al.) and one in 2019 (Reyes-García et al.), give a comprehensive overview of the global research concerned with local observations of climate change and observed climate change impacts. All three reviews compiled (1) observed changes in the weather and climate system itself – e.g. in precipitation. temperature– and (2) observed impacts on physical, (3) biological and (4) socioeconomic systems attributed to climate change.

2.5.2.1. Geographical distribution

Two of the above-mentioned reviews (Savo et al. 2016; Reyes-García et al. 2016) also investigated in which areas of the world observations of climate change and climate change impacts have been made. Reyes-García et al. (2016) present that observations of climatic change and climate change impacts have been reported on all inhabited continents of the world. However, these indicators are unevenly distributed among different regions and climate zones. Studies reporting local indicators of climate change mainly concentrate on tropical regions - especially in Africa –, the Himalayan region and Polar regions. The tropical climate is the most represented, then the temperate climate and last the polar, cold and arid climates. (Reyes-García et al. 2016)

These findings on the geographical distribution coincide with the results of the review of Savo et al. (2016). The authors of this review add that only few studies have been focusing on local observations of climate change and climate change impacts in subsistence-oriented communities in Central and Eastern Europe and the Mediterranean. Such blind spots do not necessarily imply that those areas are not impacted by climate change or that local knowledge of climate change is absent but they might originate from other causes, e.g. non-recognition of local observations, underestimation of local vulnerability to climate change, lack of research funding or political instability (Savo et al. 2016).

Another factor hampering the closing of these geographical gaps might be an insufficient communication and collaboration among the research community devoted to local knowledge on climate change. Forming a community of practice (i.e. researchers, indigenous peoples and local communities, practitioners, decision-makers) could lead to the collection of sufficient and geographical evenly distributed data in a coordinated way, supported by concepts like citizen science or community-based environmental monitoring. Such an approach might help to upscale place-based climate knowledge, providing resolutions that can impact climate change research and policy on a global level. (Reyes-García et al. 2019)

2.5.2.2. Methodological approach

Beside the unbalanced geographical extend, research on local indicators of climate change shows further biases. According to the review of Reyes-García et al. (2016) primary data on observations in general is not abundant. Among the detected studies, many do not follow a consistent methodological approach. In the reviewed studies mainly qualitative data collection methods were applied and only few of them in combination with quantitative methods (Reyes-García et al. 2016; Reyes-García et al. 2019). Many studies only provided incomplete descriptions of their methodology, omitting for example information about sampling strategy, size or study duration (Reyes-García et al. 2016).

The mentioned weaknesses emphasize the need to standardize the methodological approach in future research on climate change observations (Reyes-García et al. 2016). Such an approach should allow the collection of place-specific knowledge, which is yet comparable to the findings from other locations (Reyes-García et al. 2019). Trying to capture the holistic insights of complex social-ecological processes trough local knowledge in a standardized manner could promote the transferability of local observations into global climate change research. A stronger and continuous collaboration with the local knowledge holders, shall ensure that the historical and contextual complexities are considered when interpreting local observations (Reyes-García et al. 2019).

A first step in the direction of a more systematic examination would be a consistent categorization of local observations of climate change and impacts. This could facilitate the pooling of different place-based data sets and their integration in the global climate change research (e.g. comparability with IPCC data) (Reyes-García et al. 2019; Reyes-García et al. 2016).

2.6. Climate change adaptation on a local level

Climate change adaptation is approached from different viewpoints. It is argued that within the context of rural livelihoods, development strategies and institutional interventions often neglect to build on already existing strategies that individuals or communities apply to strengthen their adaptive capacity (Agrawal and Perrin 2009). Also, what local populations perceive as relevant climate and non-climate related stressors, as well as the related local concerns and needs, is often overlooked (Byg and Salick 2009). Past climate change debates are also reported to have underestimated the role of individuals, cultures and societies in developing and actually practising adaptations (Nelson et al. 2009) and to favour technological and infrastructural modes of adaptation (Eriksen et al. 2011). A stronger inclusion of local communities in decision-making processes and drawing on local ecological knowledge is suggested as a more bottom-up approach to human adaptation to climate change on the community, household or individual level (Eriksen et al. 2011).

2.6.1. Contribution of local ecological knowledge

The potential role of local, traditional or indigenous knowledge in adaptation to climate change is gaining academic (Berkes et al. 2000; Gómez-Baggethun et al. 2013; Naess 2013), as well as political recognition (e.g. IPCC, CBD) worldwide. The 5th IPCC report (2014) acknowledges that LEK can serve as major resource for climate change adaptation planning and implementation, as it would enhance the consideration of different interests, circumstance, social-cultural contexts and expectations during decision-making processes.

LEK results from constant adaptation of societies to different environments and social-ecological changes (climate and not climate related), on individual as well as on community level (Naess 2013). Therefore, LEK systems are constantly renewing through learning-by-doing, experimentation and knowledge building (Berkes 2018, pp. 191–200). This also requires the integration of new forms of knowledge suitable for present conditions and disregarding knowledge elements, that seem obsolete or out of use (Gómez-Baggethun and Reyes-García 2013). So LEK itself has an adaptive nature.

A more profound conceptualization of the relationship between TEK/LEK and adaptation has only been scarcely discussed in literature (Pearce et al. 2015). Yet, one consideration is to understand TEK/LEK as one element of adaptive capacity, which provides different information/competencies that can be used in synergy with other elements (e.g. access to capital resources; sharing networks or availability of time) to achieve adaptation (Pearce et al. 2015). However, the possibility to draw on LEK for adaptation depends on a society's ability to generate, transform (hybridize), transmit and apply LEK (Gómez-Baggethun and Reyes-García 2013), a mere documentation of LEK would be ineffective (Gómez-Baggethun et al. 2013).

There are different ways in which LEK/TEK can contribute to adaptation. One is through local people's awareness of climate change and its consequences. Another is based on adaptation strategies or measures strengthening adaptive capacity which are derived from LEK/TEK.

2.6.2. Awareness of climate change and motivation to adapt

Local observations of climate change can provide a high-resolution insight into climate change. Also, they help to understand the actual impacts of climate change in people's lives within a specific cultural and social context (Byg and Salick 2009). This knowledge can reflect people's concerns and needs, which are essential to consider when aiming to identify or develop locally appropriate and culturally relevant adaptation measures (Pearce et al. 2015).

Furthermore, the way in which local people perceive climate change can influence if and/or how (e.g. long- or short-term measures) they respond to it (Gómez-Baggethun et al. 2013). Beside factors like capital, time or health resources, motivation also plays a role in adaptation. Motivation to adapt might depend on the personal risk perception and on the perceived personal adaptive capacity. Not climate related stressors might be perceived as much more urgent for adaptation than climate change. Personal risk perception encompasses people's perceived probability of being exposed to climate change impacts and the perceived severity of these impacts in relation to other urgent challenges in life. Personal adaptive capacity means human's subjective perception of their ability to adapt, which can be an under- as well as an overestimation of the objectively possible adaptation. Such perceptions can for instance be shaped by religion. For example, people might think that they have only little personal control over global or regional environmental problems like climate change (underestimation) or they might have the illusion that they are in full control of nature (overestimation). In both cases human actors might not respond to climate changes as would be possible or needed (Grothmann and Patt 2005).

People's worldviews and their associated value system do not just impact the personal motivation to adapt but also influence whether planned adaptation strategies are considered worthwhile and which barriers and limits to adaptation are perceived (Adger et al. 2009; Adger et al. 2013). This subsequently affects the success of the implementation of an adaption measure designed by any political entity (Gómez-Baggethun et al. 2013). LEK/TEK is argued to provide a better understanding of the local belief systems in the context of climate change and the related local approach to adaptation, helping to design adaptation strategies which are attuned to local value systems and priorities (Gómez-Baggethun et al. 2013).

2.6.3. Existing adaptations

Not only local people's perceptions of climate change and adaptation is valuable, but also the own, autonomous ways they have already developed to adapt to climate change. LEK includes practical knowledge and experience of managing dynamically changing socio-ecological systems in ways that can enforce a system's adaptive capacity, thereby reducing its vulnerability and enhancing its resilience (Berkes et al. 2000). Various such LEK intrinsic practices/behaviour have been documented in different case studies on local communities around the world (e.g. Galloway McLean 2010). Indigenous and local people are credited with enhancing adaptive capacity through (1) conservation of plant and animal diversity, (2) diversified land use and mobility, and (3) with the help of social and cultural institutions (Nakashima et al. 2012). The most often mentioned example is the contribution of LEK systems to sustain biodiversity, ecosystem services, or even broader, biocultural diversity (Nakashima et al. 2012; Gómez-Baggethun et al. 2013). While genetic diversity is for example implemented by the preservation and use of a diversity of crop species and varieties and livestock breeds, diversification also takes place of the landscape level. This includes land use and management which enable the multiple use of only one area (e.g. pasture, forest and cultivation). Mobility enables utilization of extensive landscapes, with low fertility and sparse vegetation, or to move during sparse periods, for example caused by local climate problems (e.g. drought events). Besides mobility and the diversification of land use also, the social and institutional organisation within local communities is essential to adaptation, as they influence a community's ability to act collectively. This includes for example managing land and resources with the support of social mechanisms and customary governance structures in order to enable equitably access to resources (Nakashima et al. 2012).

3. Theoretical framework

3.1. Classification framework: Local indicators of climate change impacts

As mentioned above (chapter 2.5.2.2. Methodological apporach) the elaboration of a systematic framework to classify local observations of climate change and impacts, would be important to overcome methodological biases and to allow for more comparability of data (Reyes-García et al. 2019; Reyes-García et al. 2016). With the assignment of local indicators of climate change Reyes-García et al. (2016) provided a starting point for such a classification. Continuing these efforts, Reyes-García et al. (2019) propose a system inspired by the IPCC's 5th Assessment Report (Cramer et al. 2014). The framework used for this study in East Tyrol was based on the suggested framework of Reyes-García et al. (2019), which is described below (see also table 18, Annex).

Starting from a list of quotes of local peoples' direct observations of changes in local weather and climatic variability as well as changes in local social-ecological systems which are attributed to climate change, observations relating to the same phenomenon are grouped together. In a second step these groups are assigned to "local indicators of climate change impact" (LICCI), which are more general descriptions on the specific observations. Thirdly, the LICCIs are put in groups, based on the natural element or process reportedly being impacted. Each of the resulting groups are assigned to one of 19 sub-systems (table 18, Annex), which are eventually corresponding to the four main systems: climatic, physical, biological and human. For example in the review (Reyes-García et al. 2019), the observation "spring has been occurring earlier in the year and at a faster rate" (Tam et al. 2013) was assigned to the LICCI 'changes in the timing (onset and end) of seasons'. This indicator refers to the impacted element 'duration and timing of seasons', which is corresponding to the subsystem 'seasonal events' of the climatic system.

As in mountain areas natural hazards are a commonly reported climate change impact (APCC 2014), an additional "climate induced natural hazards" sub-system was thought to complete the category of climate change impacts on the physical system suggested by Reyes-García et al. (2019). The IPCC (2014) defined hazards as "*the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts."* Within the context of the European Alps, avalanches, rockfall, dynamic flooding (mountain torrents) and mudflows were considered as relevant natural hazards and were added to the list of impacted elements.

3.1.1. Global overview

The reviewed local observations of climate change and climate change impacts (Reyes-García et al. 2016; Savo et al. 2016; Reyes-García et al. 2019) organized in the proposed classification system shows that most changes have been observed in the climatic system, followed by the physical system. The observations in the climate system have been predominantly mentioned by non-indigenous people and people whose livelihoods are not based on the direct use of natural resources (i.e. non-rural people). However, the highest diversity of local indicators of climate change has been found in the physical and biological systems, with a high portion mentioned by indigenous people (Reyes-García et al. 2016). In comparison to impacts reported in the 5th IPCC report, some changes are rarely (e.g. impacts on ocean salinity and currents) or not at all (e.g. impacts related to soil salinization or ocean acidification and hypoxia) registered by local observations. Vice versa, some locally observed impacts do not appear in the IPCC (e.g. impacts on hunting and wild food collection). Yet, further changes resulting from impacts only reported by the IPCC (e.g. soil salinization), sometimes come to light through local observations on biological systems (e.g. changes in the wild flora). (Reyes-García et al. 2019) The least observations of changes have been mentioned in the human system (Reyes-García et al. 2016; Reyes-García et al. 2019).

3.1.1.1. Local observations of climatic changes

Following the classification system suggested by Reyes-García et al. (2019), the climate system comprises of observed changes in climatic variables and associated changes in seasonal events. Precipitation is the most frequently observed changing climate variable – especially in mountain areas and equatorial zones (Savo et al. 2016) – including variations in the mean and distribution of precipitation (Reyes-García et al. 2016). Observations referring to temperature mainly report of changes in the mean temperature (i.e. warming trend), as well as an increase in temperature anomalies and fluctuations (i.e. extremes) (Reyes-García et al. 2016; Savo et al. 2016). In many alpine ecosystems, the increased air and water temperatures have been associated with the observed melting of glaciers and permafrost, which is triggering a cascade of further impacts, such as changes in animal behavior, distributional shifts of plant species and an increase in pests and diseases (Savo et al. 2016). Observations mentioning alterations in wind patterns were also abundant (Reyes-García et al. 2016).

Further observations also included more multilayered phenomena (Reyes-García et al. 2019), like changes in seasonal events (e.g. shifts in the seasons, changes in monsoon patterns) and drought patterns, which are linked to significantly unfavorable consequences for food production systems (e.g. agriculture, hunting, fishing) (Savo et al. 2016). Although an increase in extreme weather events (e.g. heavy rainfalls, storms and hurricanes) has been observed in different localities (Savo et al. 2016), most local observations are rated as slow onset impacts (i.e. gradual trends observed in long timescales) (Reyes-García et al. 2019).

3.1.1.2. Observed impacts on the physical system

The second category, according to the classification system of Reyes-García et al. (2019), comprises of observed impacts on marine and terrestrial physical systems, which are resulting from changes in the climatic systems. The most frequently observed impacts are reported in the cryosphere (e.g. changes in snow cover, sea/lake/river ice, glaciers, ice sheets, permafrost) and in hydrology (Reyes-García et al. 2016). A common observation is the reduction of freshwater in quantity as well as in quality, whereas in many arid and humid areas of the world the frequency and severity of floods and landslides is reported to increase (Savo et al. 2016). Observations on impacts on marine systems are less abundant, often reporting sea-level rise and associated coastal erosion (Savo et al. 2016). Only few impacts on soil systems (e.g. soil moisture or erosion) have been observed (Reyes-García et al. 2016). Almost all observations are rated as slow onset impacts (e.g. permafrost) (Reyes-García et al. 2019)

3.1.1.3. Observed impacts on the biological system

The third category pools the observed effects of temperature changes and other climatic variabilities on morphology, abundance, distribution and migration patterns of plant and animal species in wild/untended/not-managed terrestrial as well as marine systems. Most changes have been reported in the terrestrial systems, like in the abundance of wild plant species or changes in their phenology (i.e. to the timing of flowering and fruiting) (Reyes-García et al. 2016; Savo et al. 2016). Changes in seasonal events are also frequently mentioned (Reyes-García et al. 2016), like timing and duration of seasons (e.g. mating season) or changes in migration or hibernation patterns (Savo et al. 2016). Especially in northern latitudes and mountainous areas, shifts in animal and plant species ranges to the cooler northern latitudes or to higher elevations has been observed (Savo et al. 2016). A loss of plant and animal biodiversity due to climatic variations, is particularly reported in tropical and piedmont areas (Savo et al. 2016).

In general, the observed impacts on biological systems are very diverse (Reyes-García et al. 2016) and are mostly rated as slow onset impacts – of the few rapid onset impacts (i.e. abrupt changes and/or extreme episodic events) most are forest fires (Reyes-García et al. 2019).

3.1.1.4. Observed impacts on the human system

The fourth category represents observed impacts on the human system, directly caused by climatic changes or indirectly by changes in the biophysical environment. These range from impacts on managed systems (e.g. agriculture, forestry, fisheries) over social inequity to effects on the human health and nutrition (Reyes-García et al. 2016; Savo et al. 2016). Despite the assumption that local people must experience the consequences of climate change at first hand due to their direct dependence on natural resources, the least impacts have been observed on the socioeconomic system. This might be because there are so many other drivers of socioeconomic change beside climate change (e.g. integration in market economies, specialization, migration), which have more direct and immediate impact on people's lives and are often difficult to distinguish from each other (Reyes-García et al. 2016). Savo et al. (2016) also argue that, in comparison to other climate change impacts, changes in the socioeconomic system are harder to quantify. On the basis of different case studies, however, they highlight that "climate change has significant potential to disrupt the social fabric and culture of many communities", e.g. through conflict around limited resources, longer migration routes for nomadic herders, loss of traditional practices or cultural important habits (Savo et al. 2016).

The most frequently observed changes occur in agricultural and in forest systems (Reyes-García et al. 2016; Reyes-García et al. 2019). Commonly mentioned changes are a decrease in crop production and/or quality, often combined with increases in pests and diseases (Savo et al. 2016). In contrast to the results of the 5th IPCC report, only few mentions of impacts on the human health (e.g. effects of extreme heat events, increased prevalence of vector-borne disease) have been found (Reyes-García et al. 2019).

3.2. Classification framework: local adaptation to climate change impacts

As mentioned earlier, climate change adaptation is urgently needed (Agrawal and Perrin 2009), adaption processes consist of various dimensions (Smit et al. 2000), are regularly limited by different barriers (Biesbroek et al. 2013) and can be led and informed by local ecological knowledge (Byg and Salick 2009; Gómez-Baggethun et al. 2013). Attempting to consider all of these aspects when investigating local climate change adaptation within this thesis, the following definition of adaption was adopted: *Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities.* (Moser and Ekstrom 2010, p. 22026) Within this thesis, the term adaptation refers both to specific climate change adaptation actions as well as to more indirect behaviour patterns/habits, which are strengthening the adaptive capacity of local communities to respond to climate change impacts (Smit and Wandel 2006).

To be able to compare the collected local adaptation strategies to climate change impacts across different climate zones, geographical regions and livelihood activities, the classification framework was based on the 3-level classification system developed by Schlingmann et al. (2021). In this system, adaptation measures are attributed to "sectors", "domains" and "types". The "sector" describes in which main natural resource dependent livelihood activity an adaptation takes place (i.e. crop cultivation, livestock farming, household). The "domains" describe more precisely in which form the adaptation takes place. A distinction is made between changes affecting the livelihood activity as a whole and livelihood related activities (e.g. timing, location, livelihood products, productive resource inputs, social and human capacity building). The "type" distinguishes between quantitative, measurable changes (e.g. saving water) and qualitative changes (e.g. better cooperation between farmers). In total the classification system consisted of 6 sectors (i.e. crop and tree cultivation, livestock husbandry, fishing, hunting/gathering, aquaculture, household), 7 domains, 13 qualitative and 5 quantitative types (table 19, Annex) (Schlingmann et al. 2021).

Applying this classification system, Schlingmann et al. (2021) reviewed current literature related to local adaption to climate change and gave an overview of the "*global range, variability and commonalities*" of the identified adaptation measures across different climate zones, geographical regions and livelihood activities.

3.2.1. Local adaptations across climates

Globally, local adaptation measures showed a larger diversity within than between climate zones, which means that similar adaption strategies have been found in different climate zones. One conclusion was that local adaptations are more often shaped by livelihood activities than by climate zones. It was assumed that within specific sectors people apply similar strategies (e.g. changing cropping patterns) across different climate zone, but on a more detailed level these responses differ depending on the prevalent climate (e.g. different species or varieties are used in different climate zones) (Schlingmann et al. 2021).

3.2.2. Local adaptations across livelihood activities

Most of the classified local adaptation measures involved changes in aspects of natural-resources-based livelihood practices. The most common responses were documented in the cultivation sector. A third of all identified responses were not directly related to natural resource dependent livelihoods. This included for example changes in household and community assets, like social networks (e.g. sharing tangible and intangible resources), infrastructure or biodiversity conservation. Many of the found adaptation measures were identified as behavioral changes, especially in relation to applied methods and techniques. Management, planning and knowledge transfer, though, were found to play a minor role. The literature review was thought to have mainly captured more spontaneous and reactive adaptation activities (e.g. coping, adjusting and securing). In total, more of the identified adaptation measures imply qualitative than quantitative changes. (Schlingmann et al. 2021)

3.2.3. Local adaptations across geographical regions

A geographical bias has been identified, as most of the reviewed case studies related to local climate change adaptation were located Asia and Africa (70%), while only 15 % were found in Latin America 15%. Some of the reviewed adaptations could not be identified as "local" or "indigenous", as they were externally driven and/or scientifically based. The application of chemical fertilizers and pesticides or shifts towards off-farm work were common example of such adaptation measures. (Schlingmann et al. 2021)

4. Methods

4.1. Project cooperation

Part of data collected within the master thesis might be incorporated in the global study project "Local Indicators of Climate Change Impacts" (LICCI) of the Universitat Autònoma de Barcelona[1]. Within this project, research partners are collecting data in different study sites around the world, which are proportionally distributed across the five different main climate-types defined by Köppen-Geiger (i.e. A: equatorial, B: arid, C: warm temperate, D: snow, E: polar) (Peel et al. 2007). At all the different field sites, the same methods are used to collect data on LICCIs and on local adaptation or coping measures. The data collected in Eastern Tyrol contributes information about local climate change impacts and adaptations in the alpine zone, covering the alpine climate-type (Rubel et al. 2017). To ensure the comparability of my data with other LICCI case studies, I applied the methods developed by the LICCI project for all its studies (LICCI 2020).

4.2. Study site

My research starts from the assumption that also in the Western European context, people who are still working and living in close relation with nature, established place-specific knowledge system through their daily practical experiences and observations over many years and generations. Therefore, I decided to use the term local ecological knowledge throughout my study investigating the peculiarities of the environmental and climate conditions through the lens of local people – primarily farmers, foresters and hunters - of three communities in a rural setting in the Austrian Alps.

4.2.1. Selection

The selection of Eastern Tyrol as study site in Austria was guided by the criteria that the site's inhabitants must have lived in intimated interaction with their local environment for a long period of time, which is, among other things, expressed in a high dependency of the local population on natural resources for their livelihoods (e.g. by practising agriculture, hunting-gathering, fishing and/or animal husbandry/pastoralism). Areas in which, until now, no or only few studies of local indicators of climate change have been conducted were preferred.

[1] For further information on the LICCI project see //licci.eu/.

4.2.2. Characterization

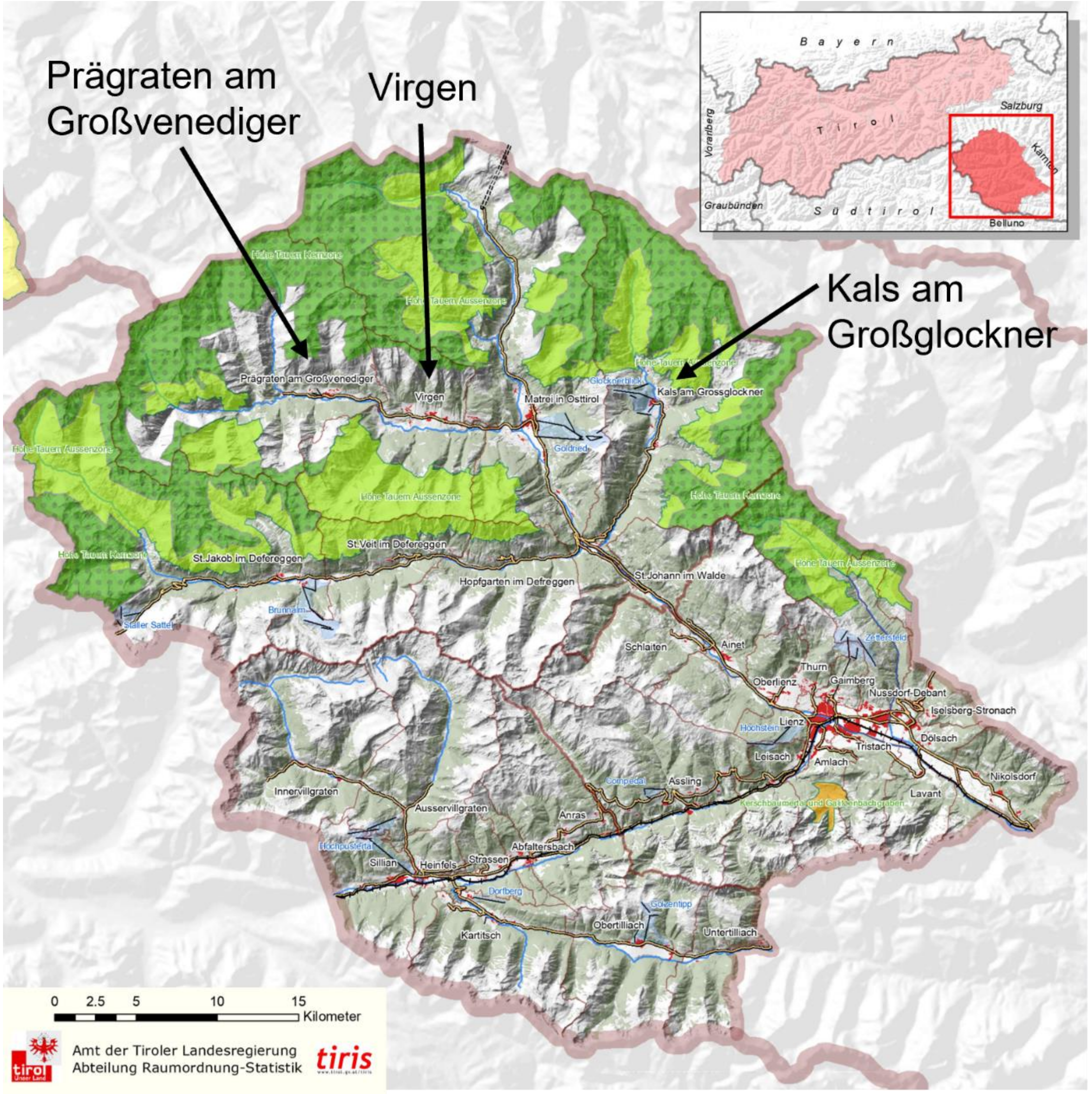

Figure 2 Map of Eastern Tyrol with the study communities Prägraten, Virgen and Kals and the Nationlpark Hohe Tauern zone (light and dark green) indicated (adapted from Tiris 2009).

The data collection took place in the region of Eastern Tyrol, which is congruent with the political district Lienz, the largest district of the state of Tyrol (Austria) (table 3). Lienz is located in the Austrian part of the Eastern Alps, south of the Alpine divide. It belongs to Tyrol but has no direct border with the rest of the state. In the North Lienz, borders the state of Salzburg and in the East the state of Carinthia, as well as Italy in the West and South (Ingruber 2001) (figure 2).

It has a surface of 2020 km^2, of which only 8.7 % are permanent settlement area (effective 2018, Amt der Tiroler Landesregierung 2019). The district is divided in 33 communities, with Lienz being the district's capital (Amt der Tiroler Landesregierung 2019). In total, 48,753 people are living in Eastern Tyrol, which leads to a population density of approx. 24 inhabitants/km^2 (table 1; Statistik Austria 2019). 32 % of the district are covered by forest and 46.3 % are agricultural land (Tirol Atlas 2001). One third of the total area of Eastern Tyrol and 10 of its 33 communities lie within the nature conservation area of the National Park Hohe Tauern (Stotter 2018, pp. 129–131).

Table 3 General data of study area (Statistik Austria 2019; WKO 2018)

	Inhabitants	Population density (inhabitants/km²)	Area (km²)
Austria (republic)	8,858,775	106	83,882
Tyrol (state)	754,705	60	12648
Lienz (political district)	48,753	24	2020

The region is characterized by the mountain landscape, hosting the mountain range of the Hohe Tauern in the North and the Carnic Alps and the Lienzer Dolomits in the South. The altitude ranges from 500m up to 3797m and include the highest mountain of Austria, the Großglockner, which is situated in the Hohe Tauern on the border between Eastern Tyrol and Carinthia (Tirol Atlas; Katholischer Tiroler Lehrerverein, p. 8).

Eastern Tyrol socio-economic development was shaped by its location in the middle of the mountains and its geographical separation through Salzburg from North Tyrol in 1918, when South Tyrol became Italian territory. Due to this peripheral location Eastern Tyrol was economically disadvantaged in comparison to the rest of Tyrol (e.g. limited mobility, material, goods and information flow). For a long time the local economy was dominated by agriculture and small business. This started to change in the phase of reconstruction after the second World War with the building of a road (Felbertauernstraße, 1967) which opened a North-South connection via Eastern Tyrol. Following this event, also the tourism sector evolved quickly and became an important economic branch. In the 70ies, the establishment of bigger companies initiated an industrialisation process in the district. Consequently, the number of people working in agriculture declined, while it rose in the industrial/commercial, service and tourism sectors. Of 21,906 employed people in 2017 in the district of Lienz 7% were working in agriculture and forestry, 32% in industry/commerce (incl. construction) and 61% in the service sector (incl. tourism). From 1960 till 2010 the number of agricultural and forestry holdings declined from 3,080 to 2,545. Of the remaining 2,545 exploitations 26% were full-time farms, 56% part-time farms and 18% legal entities or groupings[2] (Amt der Tiroler Landesregierung 2019).

4.2.3. Selection of communities

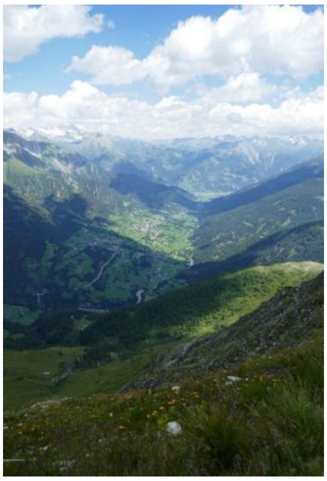

Figure 3 View over the western part of the "Virgental" (Fuchs, 2020)

When selecting the communities, the aim was to choose (a) relatively homogenous communities in terms of ecological and cultural conditions and (b) communities which are representative of the environmental and socio-cultural conditions of the study site (e.g. no especially favourable or unfavourable conditions).

To ease logistics for the later sampling of study participants, communities with a size between 20 and 500 households were preferred. Due to time and budgetary limits, the number of communities was restricted to three.

For the selection process the "Regionsmanagment Osttirol" (RMO; regional management Eastern Tyrol) association was consulted as a local informant. The association suggested communities which would fit the above-mentioned criteria, and which were considered receptive to the topic of the study.

Finally, the three communities Prägraten am Großvenediger, Virgen and Kals am Großglockner, all located within the area of the National Park Hohe Tauern agreed to participate in the research

[2] Juristische Personen und Personengemeinschaften

project. The communities have a population size between approximately 1100 and 2100 inhabitants (table 4; effective 2017, Statistik Austria 2019). All three are in close proximity with a maximal distance of 33,5 km (20,6 km linear distance). The communities Prägraten and Virgen however are located in the valley "Virgental" (orientation east-west) (figure 3), while the community Kals lies in the valley "Kalser Tal" (orientation north-south). Both valleys merge into the Iseltal, one of the three main valleys of Eastern Tyrol (Katholischer Tiroler Lehrerverein 2001, p. 8).

Table 4 General data of research communities (Statistik Austria 2017; Tirol Atlas)

Communities	Inhabitants	Private Households	Altitude (m)
Prägraten am Großvenediger	1,126	352	1,335 m
Virgen	2,191	682	1,194 m
Kals am Großglockner	1,132	399	1,325 m

In all three communities, agricultural use consists mainly of grassland farming; arable farming is only practised to a very small extent (less than 1% of agricultural use). Cattle are the main livestock. Sheep and goats are the second most common livestock. Just over half of all farms are run as part-time farms (Tirol Atlas 2000).

Due to the topographic relief of the mountains, with the great differences in altitude and the different orientation of valleys, the weather in Eastern Tyrol is described as very complex. Mountain ranges deflect air currents and weather fronts, thereby delaying, mitigating, or reinforcing related weather phenomenon. Generally, atmospheric disturbances mainly arrive from the South. Weather conditions from the South are seldom but can have a great impact. The prevalent wind direction is west to northwest. The Hohe Tauern constitute a weather divine: wind currents arriving from north, northwest cause rain and snowfall directly at the Hohe Tauern mountain range, while more in the south (at the level of Matrei) the sky can be uncovered. This is due to the so called „Tauernwind", a northern downslope wind, which heats up and loses moisture as it sinks. The frequent occurenc of the "Tauernwind" is the reason for the comparatively mild and sunny weather of Eastern Tyrol for this altitude (Staller 2001, pp. 107–109) .

The „Tauenrwind" is especially strong in north-south oriented valleys like the Kalsertal, while west-east oriented valleys like the Virgental are protected from the wind. In Kals and the Virgental, the warm air arriving from northwest brings more precipitation, than low-pressure events in the south of the alps. Specials are weather conditions in which low pressure developments occur in upper Italy in conjunction with cold air advances into the western Mediterranean Sea. Depending on the location of this small-scale low-pressure area in Italy, extreme precipitation can occur in East Tyrol in a short period of time. In summer and autumn, this can lead to the risk of flooding and in winter to extreme amounts of fresh snow. Long, stable periods of good weather in summer are due to the Azores High. The frequency of summer thunderstorms decreases towards the Hohe Tauern, as the snow and glacier areas slow down convection (Staller 2001, pp. 107–109).

In comparison to other Eastern Tyorlian communities, Virgen is known for its mild climate. The mountains of the Venedigergruppe shield it from the cold "Tauernwind" in the North, while in the South the mountains of the Lasörlinggruppe are low enough to even permit up to four hours of sunshine on the shortest days of winter. The mild climate enables the cultivation of fruits, yet this only makes up a very small part of Virgen's agricultural use (Pawling 2001, p. 407).

Virgen and Prägraten are partners of the "Klimabündnis Tirol" (Klimabündnis Tirol 2020) and already participated in a project analysing the risks of and adaptation to climate change in the communities' area. The project involved only a small number of experts, but not the local population as a whole (Energie Tirol, alpS GmbH, Klimabündnis Tirol 2019). Both communities are also involved in the “Sonnenregion Hohe Tauern” which is one of Austrians “Klima- und Energie- Modellregion”, engaged in regional climate protection projects . Because of these previous experiences, those two communities were considered as being already sensitized to the topic of environmental and climate change.

4.3. Sampling

For the data collection semi-structure interviews and focus groups were conducted. Both of them had different criteria for sampling the interviewees within the selected communities. In all cases non-probability sampling was applied, as the aim was not to make generalised statements about the studied population but to explore people’s knowledge and views on a specific topic in depth (Newing et al. 2011, p. 67). An overview of the number, age and background of all participants in the semi-structured interviews and focus group discussion is presented in table 5.

Table 5: Demographics of sampled study participants (n=35) of the semi-structured interviews (SSI) and the focus group discussions (FGD).

Variables	SSI (Local context)	SSI (Observations of change & adaptation)	FGD participants (Observations of change)
	n= 5	n= 18	n=12
Sex			
Female	1	8	1
Male	4	10	11
Age (years)			
< **40**		2	1
40 to 65	3	11	8
> **65**	2	5	2

4.3.1. Semi-structured interviews

The semi-structured interviews were divided in two parts, aiming for different types of information. Due to this they had different sampling requirements, which are described below.

4.3.1.1. Local livelihoods and local timeline of events

The aim of the first semi-structured interviews was to get an in-depth understanding of the local context considering (1) local livelihoods and dependency on the natural environment, as well as (2) the timeline of events that are important to the community. Most knowledgeable individuals living in the research communities for already a minimum of 30 years were preferred for these interviews, as they should be able to provide information on inform about the local livelihoods and local timeline of events. The interviewees were selected via convenience sampling, which is often used in the exploratory phase of studies to gain a first idea of the research site and subject (Newing et al. 2011, p. 72), thereby allowing for tuning of the following research steps (e.g. key-informant selection; categories for quota sampling). In this case, the municipalities of each community were asked for recommendation of persons who are known for their interest in the village, its inhabitants, its surroundings etc., who have been living on site most of their life and who would be willing to share their knowledge. In total 5 interviews were conducted, representing all three communities (2 in Kals, 2 in Virgen and 1 in Prägraten), until a point of information saturation was reached.

4.3.1.2. Perceived changes, drivers of changes and adaptation/coping measures

In a second step interviews aiming to find out about (3) perceived changes in the local environment and the corresponding drivers and (4) adaptation/coping measures to these changes, were conducted.

In this case, the aim was not to obtain only experts' knowledge, but the diversity of knowledge within the site. Therefore, individuals of different age and gender engaging in different livelihood activities, were targeted. As the plan was to investigate these specific sub-groups of the local population and the overall study is considered small scale, quota sampling was chosen as the best suited sampling strategy (Newing et al. 2011, pp. 72–73). To select the interviewees within the quota, snow-ball sampling was applied (Bernard 2018, p. 150). In the beginning key-informants (i.e. mayor, municipal clerk, interviewees of the first interview section were asked to (1) list people they knew, who fitted the sampling criteria, and (2) recommend one person from the list for the next interview.

The quota sampling was based on the design of a sampling grid (table 3) which contains three different categories: livelihood activity, age, gender (Bernard 2018, pp. 146–147). The most common local livelihood activities which are directly related to natural resources were identified based on the information obtained in the interviews about the local context. Hence, "agriculture", "forestry", "hunting" and "others" were chosen as the categories for livelihood activity. The fourth category "others" represents people who are known in the communities for spending a lot of time in nature and for attentively observing natural processes (beekeepers, hiker, mountaineering guides, local avalanche commission etc.).

Ideally at least three individuals of each category (livelihood activity, age, gender), should be interviewed. The age categories included young (under 35 years), middle aged (35 to 65 years) and old women and men (over 65 years). The aim was that each age category should be represented of minimum three interviewees and, within each age category, at least three individuals should be female and three should be male. Following this sampling design, a minimum of 18 interviewees should be sampled. This was to translate to 15-20 interviews, as one person might fit into more than one livelihood categories (e.g. farmers who hunt; apiculturists who are farmers).

Table 6: Quota sampling grid with number of participants (n= 18) per quota (livelihood activity, age and gender).

Age (years)	Sex	Agriculture	Forestry	Hunting	Other	Total
Under 40	women					-
	men	2	1	1		4
From 40 to 65	women	5	1	1	1	8
	men	3	1	3	2	9
Over 65	women	1		1	1	3
	men	3	1	3		7
Total		14	4	9	4	

Ultimately, however, the quota sampling was less balanced than planned. Male, 40-65 years old interviewees following an agriculture related livelihood were most strongly represented. The underlying reasons are discussed in chapter 6.1. "Methodological limitations and poteintial biases". In total 16 persons were interviewed, five in Kals, four in Virgen and seven in Prägraten and two informal interviews/conversation Kals and Virgen were conducted. Table 6 shows how many interviewees represented each quota. Interviewees who are engaged in several of the mentioned nature-related activities were counted in each livelihood categories, independent whether the activity is carried out full- or part-time or only in their free-time. Thus, some interviewees were counted twice or thrice.

4.3.2. Focus group discussion

The aim of the online focus group discussions (FGDs) was mainly to discuss and validate local indicators of climate change impacts which were mentioned by individuals during the semi-structured interviews. It was also intended to give the participants the opportunity to identify new indicators of climate change impacts which have not yet been reported by other individuals. Thus, the participants of the FGDs should ideally be individuals living at the study site, who (a) practice the different livelihood activities than the ones which were already covered in the interviews earlier, (b) be of different age and gender and (c) have a diverse expertise (i.e. preference was given to elders or local experts).

Participants were selected through convenience sampling, whereby individuals who did not yet give a semi-structured interview were preferred. The participants were either suggested by key-informants or were listed during the snowball sampling. As recommended for online FGDs, the time for the discussion was limited to max. two hours, which is also why the group size was decreased to 3-5 participants per discussion (Krueger and Casey 2009, p. 174).

In total three FGDs were conducted, one in each of the three communities. In Kals four persons participated, including one interviewee from the SSI. In Virgen three persons participated, also with one interviewee from the SSI. Due to scheduling conflicts, two more people could not participate in the FGD of Virgen but agreed to an individual telephone interview. Thus, in total five persons individuals offered input on the suggested change observations. In Prägraten three people participated in the FGD, two others had to cancel their participation at short notice.

4.4. Data collection

The data collection in the study area and online was conducted solely by myself, during the year of 2020 and 2021. I collected the data on-site from beginning of July till mid August 2020. The online part took place from January till March 2021. The data was collected in three subsequent phases, which are explained in more detail in the following. All data was collected in German.

4.4.1. Semi-structured interviews

Given the aim of the first two phases of this research project, semi-structured interviews were decided to be the best fitting qualitative data collection method. Semi-structured interviews are useful in situations where knowledge about the research topic is available, but not sufficiently to elaborate a structured interview (e.g. questionnaires) with precise questions targeting the local context (Newing et al. 2011, pp. 102–103). The preparation of an interview guide, with the questions or topics to be touched in the interview, allow for structure and thus the production of more reliable, comparable qualitative data (Bernard 2018, p. 164). Still, the questions should be sufficiently flexible and open-ended, to enable the interviewee to guide the dialogue in new directions and the interviewer to spontaneously make comments or pose follow-up questions on mentioned topics (Bernard 2018, p. 164).

The interview guide also helps to keep the interview within a certain time range, which makes semi-structured interviews a useful tool when working with people who have only limited time (Bernard 2018, p. 164) The participants for this project – individuals whose livelihood activities depend on the rhythms of nature (e.g. farmers, hunters) and community officials – were ranked among this group of people. The interviews were separated in two successive phases, for which different interview guides were designed (see annex).

Before starting the actual data collection, 1-2 pre-tests for each interview phase were done. Pre-tests are an essential step in successfully conducting interviews. Pretesting the prepared interview guide before starting the actual research process can provide constructive feedback on the questions' design, wording, the implementation of the interview itself etc. and offers a chance to further improve the process. (Bernard 2018, pp. 215–216)

4.4.1.1. Local livelihoods and local timeline of events

The obtained insight allowed to develop the interview questions for the second part of the study in a way that they better fitted the local context. Furthermore, it enabled the later interpretation of the collected data in relation to the local context.

Two out of five interviews focused on understanding the local livelihoods. The questions revolved around the main nature- and not nature-related activities inhabitants exert: which activities do they engage in; timing of the activities during the course of the year; who is active and where.

The other three interviews focused on the historical background of each community. The questions covered the topics history of the village, demographic changes, livelihood changes and past (extreme) weather/natural events. The respondents were also asked to give further explanation on the mentioned events, for example how they impacted the community and environment.

4.4.1.2. Perceived changes, drivers of changes and adaptation/coping measures

The goal of the second section of interviews was to obtain a collection of perceived environmental changes related to the climatic, physical, biological and/or human systems, including possible causes of these changes and how they affect the local population. This list of observations of change was later reviewed in online focus group discussions with other community members. Furthermore, the aim was to collect different adaptation/coping measures related to the observed changes.

The main questions of the interview focused on (1) which climatic and environmental changes people observed, (2) since when they were noticed, (3) what was thought to be the driver(s) of these changes, (4) how these changes affect the lives of the interviewees and (5) how they adapted to/coped with these changes. To learn about people's observations of change, the interviewees were guided through the 4 pre-set main categories (climatic, physical, biological and human systems), by asking questions like "did you observe any changes in the temperature". When an observation was described, I also ask for the corresponding drivers, consequences and adaptations. Following this scheme, one after the other observations of change was discussed in detail.

4.4.2. Online focus group discussion

In the third phase of the study, the individually collected observations of climate and environmental change were discussed within a group setting. For this purpose, focus group discussions (FGD), in which a group of people discusses a specific topic selected by the researcher (Bernard 2018, pp. 179–182)were chosen. FGD seemed suitable as the aim was to collect information on the participants' interactions and not only on their individual statements (Kitzinger and Barbour 1999, pp. 2–20). Through the discussion in a group, FGDs have the potential to bring forth contrasting views between participants and to inspire their reflection. They allow to collect not only this information, but also the reasoning that lies behind specific views (Newing et al. 2011, pp. 104–106). The method is also described to be effective in generating ideas and opinions (Newing et al. 2011, pp. 104–106) and in exploring participant's common knowledge on a specific topic (Kitzinger 1995).

FGDs are commonly used in conservation research (Newing et al. 2011, pp. 104–106) and were already applied in other studies which also investigated local climate change observations and adaptations (e.g. Ogalleh et al. 2012). In relation to this study, the above-mentioned attributes were thought to be beneficial, as community members with different livelihood background got together to discuss and validate local indicators of climate change impacts (LICCIs) which derived from individual observations. FGDs allowed to see whether the individually identified changes, corresponded with the collective memory. Furthermore, the discussion was hoped to bring up new issues and to lead to the identification of additional LICCIs.

Due to the COVID pandemic, group meetings in person were not possible. Therefore, synchronous online FGDs, using the online platform ZOOM, were conducted. Several studies showed that data quality of online FGDs could be equal to that of face-to-face FGDs, as for example similar themes occurred in both types of FGDs. Also, participants did not solely respond to the questions one after the other, but real discussion were reported to take place on in online FGD. (Kite and Phongsavan 2017). Furthermore, participants were expected to be more attentive to the posed questions and discussed themes, as they generally avoid talking at the same time when using audio-visuals (Fielding et al. 2017, pp. 435–448).

Yet, one limiting factor of online FGDs in comparison to face-to-face meetings is that online communication is slower - e.g. due to technical problems; slow internet connection; distraction from surrounding, shorter concentration span. Therefore less data is produced and less topics can be covered (Kite and Phongsavan 2017). In our case the number of change observations which needed to be discussed had to be reduced to fit in the intended timeframe of two hours for the online meeting. Only observations of changes which (1) impacted the physical, biological or human system and (2) which were contradictory (e.g. opposite trends for the same impacted element) or incomplete (e.g. unclear driver; one-time event or long-lasting trend) were selected for the FGDs. To further limit the number, only observations which had been mentioned by more than two people were included in the FGDs. Exceptions were made for specific changes observed by interviewees who were especially knowledgeable about specific topics (e.g. beekeepers) or who had an unique insight in certain aspects/parts of the natural world (e.g. mountaineering guides). For the discussion process, (physical, biological, human) the observations were sorted in descending order of inconsistency within each category. A certain amount of time was set aside for discussion for each category. As many of the observations as possible in the 2 hours' timespan were discussed. The remaining observations were omitted.

The FGDs were structured by an interview guide with open-ended questions (see annex). One single change observation after the other was presented verbally and via the shared screen on a slideshow to the participants. For each observation the participants were asked (1) whether they had noticed this change, (2) since when they had noticed this change, (3) what they thought was the driver of this change and (4) if/how this this change impacted them, their household, or the community. Following this sequence of questions, the prepared list of single change observations (see annex) was discussed.

In contrast to face-to-face FGDs, it is suggested to provide a rough outline of the questions or discussion themes to the participants before the online FGD takes place. This is assumed to make the time together more productive, as participants can mentally prepare for the discussion. (Krueger and Casey 2009, p. 174) In this case study, several individuals wanted to know what kind of questions they would face, before agreeing to join the FGD. Therefore, a short exemplary excerpt of the discussion guide was sent to each participant in advance of the FGDs. From my experience, this knowledge reassured participants to agree to a discussion format (i.e. online) they were not used to, guided by a person they did not know personally.

4.5. Data recording and storage

All interviews were recorded with a mobile phone. The FGDs were recorded with ZOOM and additionally with a mobile phone. Audio files, audio-video files and their transcripts (text files) are stored on the BOKU server and are only accessible with my personal password.

During the data collection period, all data was regularly backed up onto an external disk. During the duration of the research, raw data will only be deleted if requested by participants. All data was immediately anonymised after collection, by assigning IDs to each participant. The personal data and the corresponding IDs are password protected and only accessible to me and my supervisor.

4.6. Data analysis

The analysed data included 19 transcripts of audio-files from the semi-structured interviews, 3 transcripts of audio-video recordings from the focus group discussions, as well as notes from 2 personal and 2 telephone interviews. Additionally, two informal interviews/conversations were conducted during field work and the resulting information was included in the analysis.

All audio recordings were transcribed using the open-source web app “oTranscribe” (MuckRock Foundation). Abridged transcripts (Krueger and Casey 2009, p. 117) were made, which avoided transcribing irrelevant information/comments, which were not related to the study content. Data analysis was conducted in German and English. All quotes that were required in English for writing this thesis, were translated by me, with the help of the online dictionary “dict.cc” and the online translators “linguee.com” and “DeepL.com”.

4.6.1. Summarizing

All information about the local context of the study site was extracted from the 5 semi-structured interviews. Text passages of the transcripts which were considered relevant to describe the local context were transferred in a text file and assigned to the main topics (a) local livelihoods and (b) local timeline. The text passages were then condensed to short descriptive summaries.

4.6.2. Qualitative content analysis

The analysis of the 16 semi-structured interviews related to change observations and adaptation, as well as the 3 focus group discussions and the 2 additional telephone interviews was based on the qualitative content analysis described by Mayring (2010). Qualitative content analysis is well suited for single case studies with small sample size, as well as for exploratory studies (Mayring 2010, p. 23).

In the semi-structured interviews concerning the local context, interviewees already mentioned several climatic and environmental changes they had observed and adaptation/coping measures they had applied. This information was also included in the qualitative content analysis.

4.6.2.1. Coding

All transcripts and notes have been coded and annotated using the program “Atlas.ti” and “Microsoft Word”. The unit of analysis were text passages from the transcripts.

Semi-structured interviews: observations of change

In the first cycle coding of the semi-structured interviews, a combination of deductive and inductive coding was applied (Miles et al. 2020, pp. 62–75). For the change observations, the pre-established list of codes was based on the classification framework of local indicators of climate change (LICCI) proposed by Reyes-García et al. (2019). The codes were assigned to text passaged which, according to the researcher interpretation, represented natural elements or processes (e.g. seasonal temperature) which were described to be impacted by climatic and non-climatic changes. During coding, new codes and subcodes emerged, which supplemented the pre-established list of codes. For example, subcodes, which detailed the type of observations people had stated (e.g. “driver” - the observed change, is also a driver of further change), were added to the list.

Focus group discussion: observations of change

To answer the research questions, the content of the FGD was considered to be more important than the way in which statements were made or how participants interacted. Within the scope of this study the main focus was on the thematic, rather than on the contextual analysis of the FGDs (Vicsek, 2007). The output of the FGDs was thus coded according to the same principle as the SSI, applying the code system which was established during the SSI. Most of the codes were already clear, as specific change observations were proposed for the discussion. Yet, some other observations of change were mentioned and additional ones were identified during the discussion. Thus, some additional codes had to be added, and categories were refined during the coding process (e.g. natural hazard category). The final list of classified codes and subcodes is depicted in the category system (see table 16, annex).

Semi-structured interviews: adaptation measures

The same approach was applied for coding the adaptation measures of change. The codes in relation to adaptation to climate change were based on the 3-level classification system proposed by Schlingmann et al. (2021). The codes were assigned to text passages which, according to the researcher interpretation, described adaptation to the observed fully and partly climate change driven impacts according to the chosen definition[3]. Additionally, text passages in which participants described by what or in which ways these responses are or could be hampered, were coded as "barriers".

4.6.2.2. Categorizing

<u>Semi-structured interviews: observations of change</u>

According to their assigned codes (i.e. impacted element/process), the text passages were classified in the four main categories of observed changes: (1) changes in the climatic system, (2) changes in the physical systems, (3) changes in the biological systems and (4) changes in the human systems. This was done by transferring the coded statements from Atlas.ti/Microsoft Word to and structuring the data in an excel file. Each statement was labelled with an ID, which indicated which interviewee made the specific statement and the position of the quotation in the transcript. Thereby it was always possible to doublecheck to which context each statement related. Among other things, this helped to control whether the translation (from Austrian dialect to English) was analogous and to ensure that – torn from its context – the meaning was not changed or falsely interpreted during further analysis. Beside the description of the observed change, the coded statements commonly included further information (i.e. drivers and further impacts of the change; time frame of observation). This information was also listed in the excel table, together with the corresponding observed change description.

Within the four categories all statements from different interviewees which described a very similar or the same change observation were grouped together. At this state, the statements could be rearranged or put into another category, depending on where they fitted best. New observations from further interviews could be constantly added.

Once all observations from all interviews were added and categorized, the collected information was again condensed in a second excel table. Groups of statements which described the same or a very similar change observation, were condensed to more general descriptions of the observed change. Thereby it could be recorded how many people mentioned each change observation.

<u>Focus group discussion: observations of change</u>

Statements describing the same changes were transferred together to an excel spreadsheet and assigned to the participants who made the statement. Each statement was further divided into "description of the change", "causes of the change" and "impact of the change". Then a descriptive summary of each observed change was made. This summary included the description of the change, its causes and effects, and was complemented by a description of the level of agreement between the different participants on the discussed change.

The level of agreement was rated the following way: If, within the same FGD, one participant validated or falsified an observation and the others either did not clearly disagree verbally or clearly agreed, the observation was rated as "agreed" (+). If participants disagreed but a consensus could be found, this was rated as "partly agreed" (+/-). If no consensus could be found, this was rated as "disagreed" (-). To summarize the agreement on an observation from all three FGDs, it was determined that the same observation was discussed within at least two

[3] *Adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities.* Moser and Ekstrom 2010, p. 22026.

of the FGDs. “Fully agreed” was only reached if within all three FGDs the participants had agreed on an observation (FGD1: +, FGD2: +, FGD3: +), or if the participants in two FGDs agreed, while the respective observation had not been discussed in the third FGD (e.g. due to lack of time or expertise) (FGD1: 0, FGD2: +, FGD3: +). “Disagreed” meant that at least within one FGD participants disagreed. Everything in between was rated as “partly agreed”.

All observations of changes which were proposed to the group (physical, biological and human system) as well as all additionally mentioned observations of change were added to the compiled list of change observations from the semi-structured interviews. All observations which were (a) validated in the focus groups and/or were clearly identified during the SSI and (b) which were attributed to climate change were identified as LICCIs. The number of participants who mentioned single change observations during the FGDs, but which were not being discussed, was added in brackets to the number of observers from the SSI for the respective change (see table 8 to 12, results). This concerned in particular changes in the climatic system that participants mentioned as drivers for changes which were the actual subject of discussion in the FGDs (e.g. the tree-line is rising due to the increasing mean temperature). Also, the number of participants who explicitly validated a discussed observation was added to number of people who mentioned the observation at first in the SSI (see table 8 to 12, results).

<u>Semi-structured interviews: adaptation measures</u>

All coded statements were shortly paraphrased and then copied to an Excel table for further structuring. Each statement was labelled with an ID, which indicated which interviewee had made the specific statement, and the corresponding observed change impacts and barriers were noted. Beside the description of the adaptation measure, the related climate stimuli and barriers, also further information included in the coded statements was entered in the table: temporal scale (long/short-term adaptation or coping), actors or decision level (individuals/community/regional/national) and degree of execution (implemented/idea). All listed statements (and the corresponding information) from different interviewees which were ascribed to the same code (i.e. describing very similar or the same adaptation measures) were grouped together. This allowed to see how many people had mentioned each adaptation measure. According to the assigned codes (i.e.), the grouped statements were classified into the three response sectors: (1) Crop and tree cultivation (incl. Fodder) (2) Livestock rearing/ Animal husbandry and (3) Household capacities. Within each sector the grouped statements were further divided in response domains (two per sector) and types (see table 17, annex). All statements which did not fit to the prepared response type, domain and sector categories, were assigned to the category “general adaptations to climate change impacts”. All barriers which did not relate to a specific adaptation measure were assigned to the category “general barriers to climate change adaptation”.

4.7. Material and equipment

During data collection a mobile phone and a recording device were used to audio record the semi-structured interviews. Paper and pen were used to draft the timeline and seasonal calendar during the interviews, and a notebook to take notes during and after informal interviews and conversations. For the conduct of the online focus groups only a laptop with internet access and the ZOOM software (freely available for BOKU students), was required.

4.8. Ethical clearance

Without an ethics committee at the University of Natural Resources and Life Sciences Vienna and as a partner of the LICCI project, I was under the ethical clearance from the Universitat Autònoma de Barcelona (UAB) and I obliged to follow the same ethical guidelines as the LICCI core team. In this case I obtained free prior informed consent (FPIC) from all different hierarchies of the local communities (representatives and individuals). All private data is kept completely confidential and securely stored. As it was the purpose of this study to document local knowledge on indicators of climate change, intellectual property rights were acknowledged.

4.9. Permission and consent

To obtain the permission to conduct research in the three communities, the local authorities were contacted and informed about the content and aim of the study and the LICCI project, as well as the planned course of data collection. They gave their permission to conduct the study by signing FPIC forms and ensured to support the data collection as key informants.

The participants of the SSI and FGD were either contacted in person on site, or by telephone. Just like the community officials, they were informed about the study and the LICCI project in conversation and via an information sheet. They were asked to agree to their participation by singing FPIC forms. In the case of the online FGD it was left to the participants whether they wanted to send back the signed FPIC forms or to give their consent orally, to reduce the effort demanded by the distant communication. Additionally, all of them were asked for their oral permission for me to audio record the interviews/FGD and to take notes.

The consent forms included information about the further use of data, data privacy, rights of participants, return of results and contact details. The participation in the study was voluntary and participant were free to quit the study at any given moment. The collected data was anonymised, so no individual can be identified by name. Data will only be used for scientific publications and the result will be shared with the participants and the community at the end of the study.

4.10. Return of results

The outputs of the study are transmitted to each research community. All participants, the municipality and the RMO receive a summary of the collected local observations of climate change impacts and local adaptations, as well as a brief discussion of the results with literature.

5. Results

5.1. Contextualizing the perception of climate change impacts and adaptation to climate change

5.1.1. Changes in livelihoods

Respondents described all three communities to have been highly nature depended self-sufficient farming communities, that produce almost everything themselves except of the things that did not grow locally (e.g. sugar and salt), until the 1950/60ies. Mixed farming (i.e. cultivation and livestock production) was described to have been the common model. Most of the cultivable land was used for agriculture. Cereals as food and fodder, fiber plants for textile production, potatoes and other legumes were cultivated. Many different livestock species were kept – e.g. sheep, goats, cows, horses, pigs, chicken. The animal (e.g. milk, meat, wool) and crop products (e.g. cereals, flax) were processed and conserved for self-consumption and use (e.g. flour, bread, cheese, textiles). For grazing and hay production land that was not suitable for cultivation was preferred. Thus, alpine pastures were well tended and utilized. A great part of the hay for winter was made in the alpine meadows. Besides agriculture, handicrafts (e.g. smith, textile production) were essential activities in the communities. Most work was either done manually or with the help of animal power. The lifestyle was thus very work intense and demanded many helping hands. This workforce was provided by the commonly big families were everybody had to contribute to the work.

It was reported that this started to change a lot in the 1960/70ies. Several developments have been thought to be decisive for these changes: respondents said that from a certain point on, it was obligatory to insure and pay all people working on a farm, including family members. As for many this was not affordable, family members had to leave and look for other jobs, in many cases outside the communities, in other regions or abroad. It was stated that with the decreasing workforce it was not possible to do the same amount of work and thus land management changed. Also, the land consolidation in the 1960ies and 1970ies in Kals and in Prägraten, were mentioned to have additionally changed the land management. Land was tried to be redistributed so that farmers had their land less spread out and instead more around the own farm. Respondents overserved that this came along with the increasing use of machines, to replace the missing work force for (agricultural) land management. Small-scale structures, from agriculture to handicraft, were thought to progressively decrease due to these developments. This was also related to changes in the landscape, as hedges and stone-walls were partly eradicated, arable fields and characteristic management elements (i.e. Harpfen) vanished.

The respondents reported the communities decreasing self-sufficiency and their increasing economic dependency on other sectors. Tourism was named as a new important income source. Besides alpinist and ski tourism, the declaration of the Nationalpark Hohe Tauern in 1991 was mentioned as an additional attraction for tourists. Despite these developments, many young inhabitants were reported to have left and to be still leaving the communities to work and/or live elsewhere. At the present time, a great part of the local population commutes to work in Matrei, Lienz or other agglomerations. Other inhabitants work in the tourism sector or are employed by the municipality or the local agricultural/forest communities (Agrar/Waldgemeinschaften). Jobs within the community are thought to be especially scarce for women.

5.1.1.1. Agriculture

In comparison to the past, respondents described contemporary agriculture as less diverse. They stated that the cultivation of crop plants has almost fully stopped and instead grassland livestock farming is dominating. The diversity of livestock was observed to have decreased, as farmers nowadays are mainly keeping cattle and sheep. Also, more productive livestock breeds have been introduced. The hay production has shifted to the valley as cereal cultivation no longer dominates the well accessible land. Grassland management was thought to have intensified, among others, because more nutrients are being imported (e.g. import of concentrate fodder for more productive livestock breeds) and the fertilizer no longer has to be divided between crop production and grassland. The fertilization with slurry and the production of silage was mentioned to also have increased in the last years. In return, mountain meadows and alpine pastures are being less managed than in the past. With the decreasing availability of work force, mechanisation was reported to have replaced many manual labour tasks (e.g. drying plants for hay). Less people/farmers are processing/conserving agricultural products, e.g. most of the dairy farmers started to deliver milk from the 60ties on. However, Homegardens and fruit trees seem to be still well tended for self-consumption. Only few farmers are still living of agriculture only, the majority of the farms were reported to being run as part-time farms. Respondents shared the opinion that nowadays agriculture must be combined with another income source to be profitable. They stated that nowadays it is common to combine farming with tourism, by renting rooms or apartments, or working in the alpine sport sector (e.g. ski lift, mountain guiding). Also finding farm successors was mentioned as a common problem for many farms and was thought to be one important reason why more and more small-scale farms cease the agricultural activity and lease the land. Study participants shared the impression that the number of farms is decreasing while the size of the remaining farms is increasing.

5.1.1.2. Forestry

Respondents reported that most of the forest within the study area is privately owned, either by individuals or by local agricultural communities (Agrargemeinschaften[4]) and forestry cooperatives (Waldgenossenschaft). Most of the forest area within the three communities was stated to be declared as protection forest[5].

Respondent stated that the forest has been an essential part of the local subsistence farming in former times. Letting livestock graze in the wood was described as a common practice to extend the pasture area which was competing with the area for arable farming. Tree litter was taken from the forest soil as straw substitute to bed the animals in the stables, as the cereal production did not provide enough straw. Branches were cut and partly used as fodder for livestock. Local timber was used for construction and as firewood. The work was done manually or with the help animal power. Like in agriculture, respondents related the changes in the forest use to the decreasing availability of workforce and the beginning mechanization in forestry. Afforestation with *picea abies* became a trend, which partly led to spruce monocultures. Nowadays the locally grown timber was described to be rarely processed and/or used in the local communities but instead exported. In many cases forest owners were thought to no longer manage their forest parcels themselves due to lack of time and decreasing profitability among other factors. Measures to maintain the protective function of the forest were stated to be subsidized and fostered by the state.

5.1.1.3. Hunting

In comparison to the past, some respondents shared the impression that fewer landowners are hunting and that younger people show less interest in hunting. Thus, the transmission of local knowledge in relation to hunting were thought to be decreasing. Nowadays most people are employed and are thus only hunting in their free time. It was thought that hunting has become more a leisure activity than a profession. As free time is limited (e.g. only on weekends), there are less opportunities for hunting. Besides a decrease in people and time spent on hunting, the respondents also stated that the technology has changed a lot in comparison to the past (e.g. firearms with a wider firing range; hunting from the car). Furthermore, it was observed that wild animals increasingly must share their habitat with humans, as tourism and summer and winter sports activities have increased and diversified. Respondents shared the impression that game is more and more disturbed, even in quiet areas, which additionally complicates hunting. One consequence of these developments was stated to be the increase in some game population, which poses a challenge to the maintenance of protection and commercial forests.

5.1.1.4. Beekeeping

Respondents reported that beekeeping has always been a common side-activity at most of the local farms and that almost everybody had at least one beehive. They also mentioned that for some years now, beekeeping has been booming, as the younger generation got interested and many restarted beekeeping. Nowadays less of the beekeepers were thought to be property owners or managing land themselves. For many people beekeeping is still a side-activity and they only sell the honey they do not need for self-consumption. Yet, respondents stated that while in the past beekeepers were satisfied with a few kilos of honey per year, attempts were undertaken to increase the productivity through breeding over the last years. As a result, nowadays bee colonies tend to be stronger/more active and require more fodder than in the past. Due to this, and depending on the yearly weather conditions, more extra

[4] "*An agricultural community is a legal form of organisation for common property used for agriculture and forestry. The agricultural and forestry enterprise owned individually or by the family is called the ancestral property in connection with the share right in the community*." Schönhart et al. 2015, p. 6

[5] Forests which protect either human facilities or constructions or the soil from negative effects of gravitational natural hazards such as avalanches, rockfall or erosion. APCC 2014, p. 534.

feeding of beehives was reported to be required in comparison to the past. Also, the introduction of invasive alien pests (e.g. varroa mite) was perceived to have increased due to the increasing purchase and import of bee colonies and/or queen bees.

5.2. Local observations of climate change impacts and environmental change

Through the interviews and the focus groups discussions, numerous observations of changes in the climatic system as well as in physical, biological, and human systems have been obtained. From this collection, only those observations are presented in the results which (a) were mentioned by more than 2 people, (b) describe changes that were observed over a longer period of time or repeatedly and (c) were described in sufficient detail. This includes observations only obtained through SSI, observations validated in the FGD and observations newly identified during the FGD. In total this resulted in 58 observations.

5.2.1. Local observations of climate change impacts

Of all 58 observed changes, 42 were identified as directly or indirectly attributed to climate change. Those were defined as local indicators of climate change impacts (LICCI). Of all 42 LICCIs, 22 were reported to impact the climatic system, 11 the physical, 3 the biological system and 6 the human system.

5.2.1.1. Climate system

Temperature

Eleven of the 22 LICCIs which are impacting the climatic system (table 7), are changes in temperature. This includes changes in the mean and seasonal temperatures, in temperature extremes and in the sunshine intensity.

A regular observation was that the **mean temperature** has been increasing within the last years, particularly noticeable since the year 2015.

More specifically, for 15 of 30 study participants an increase in the **mean temperature** is especially apparent **in winter**. Participants reported for example that over the last years, winters became milder and that the usually long cold periods with up to minus 20°C are now reduced to only a few days with sub-zero temperatures per winter. Nowadays cold periods are regularly interrupted by warm days or phases with degrees above zero. In the past, morning temperatures of minus 25°C were common in winter, while now minus 12-15°C in the morning is common.

Ten participants also mentioned explicitly that **the mean temperatures in summer** have increased in comparison to the past. A common observation was, that it has become normal to have several days with up to 30°C in summer, while this has been an exception at this altitude (1.194 to 1.335 m a.s.l.) in the past. The summer of 2019, 2018 and 2017 have been highlighted as being especially hot. It was also remarked that nowadays June and July can already be very hot, while in former times, August used to be the hottest month. Some participants also emphasized their perception that days with especially high temperatures (i.e. **heat days**) became more **frequent** during summer.

For the **season of spring** , eight participants observed that it starts to warm earlier in the year. The months of February, March, April tend to be warmer than in the past. One participant expressed the impression that due to the warmer temperatures spring feels more like summer. Yet, in connection with this observation it was most often mentioned, that cold spells still occur/the temperatures can drop again in later spring. Thus, the mean temperature in spring was perceived to be higher but also that the onset of spring is up to one month earlier than it used to be.

Five participants also shared the perception that the mean temperature **in autumn** has increased. Moreover, it was mentioned that the season of autumn is prolonged because it seems to stay warm/mild for longer during the last months of the year (November, December).

Ten participants also noticed that the **mean temperature** is not only increasing in the valley bottom but also **in higher altitudes**. It was mentioned that during summer the zero-degree level rises to 4000 meters above sea-level (a.s.l.), which was uncommon in former times (e.g. 20 years ago). One participant stated that nowadays 17°C or more during summer are normal at an altitude of 2000 meters a.s.l., while it was cooler in the past.

Another observation made by eight participants was, **that it cools down less at night**. This observation referred mainly to summer nights, which were described to be muggier/ more sweltry and hotter than in the past. In Prägraten, for example, it was perceived abnormal compared to the past, that during summer it can still have 20°C at 10 pm.

A phenomenon that was perceived by five participants, was the **increasing/ more extreme temperature fluctuations** especially in summer, but also in winter. They described this as very fast changes between high and low temperatures, or warm and cold weather fronts. Instead of more gradual changes of temperature in the past, nowadays, the temperatures can differ a lot from one day to the next. (e.g. February: -15°C, the next day + 5°C; Summer: cold, the next day 30°C)

Five participants sense that **the sunshine intensity** has increased over the last years. They describe the sun to be more aggressive/burning/stinging and that one gets more easily sunburnt, which demands more protection from the sun (e.g. sun cream, cloths, sitting in the shadow) than in the past.

<u>Precipitation</u>

Seven LICCIs describe changes in the precipitation and are thus the second most frequently mentioned climate change impacts within the climatic system. This includes changes in seasonal precipitation, in precipitation extremes, in the distribution/ variability/predictability of precipitation and the occurrence of droughts.

The most frequently mentioned (20 of 30 participants) observation was, that **rainfall events in summer are more heavy/intense/extreme** than in the past. They were described to occur suddenly and very locally, releasing a high amount of precipitation in a short period of time. It was also described that **heavy rainfall events occur more frequently** than before. People understood the higher temperatures and longer periods of drought and heat as driver for the intensification of the rainfall events. They explained that the warmer air can take up more humidity which results, when cooled down, in heavy rainfalls.

Closely related to the increase in heavy rainfall events, five participants also stated that **the temporal distribution of rainfall** has generally changed. They had the impression that in the past it used to rain more constantly, e.g. several days in a row, or there was a short electrical storm in the afternoon on hot days. Nowadays in contrast it doesn't rain for a longer period and then there is a lot of precipitation in a short time.

This goes along with the perception of eight participants that it is **more difficult to predict when it will rain**, and also when it will snow. The weather seems to be less stable/more variable, changing faster from "good" to "bad". People mentioned that it is no longer possible to rely on certain weather patterns which were typical in the past (e.g. "Azores High" causing a long-lasting good weather period in summer).

A common observation was also that it was **drier** in the last years. Many people stated that this was especially the case since 2015 or 2017, yet others had the impression that this is already a longer lasting trend. Dry spells and periods of drought were mainly observed to occur in spring (four observers) and in summer (eight observers). The participants named several different drivers which could cause this water shortage: lower precipitation in summer and spring, less snow in winter, higher mean temperatures in spring and summer and intense heatwaves in summer. As there were multiple drivers mentioned, no clear trend (e.g. less precipitation in summer) could be identified.

Air masses and seasonal events

Further observed changes within the climatic system include three LICCIs in the air masses and two LICCIs in seasonal events.

The observations related to changes in the wind were controversial. Many people perceived an obvious **increase in the wind strength** (six observers) and **the number of windy days** (4 observers). The statement that the wind is more intense than in the past was often related to the description of the windstorm Vaia in 2018, with very high windspeeds (more than 200 km/h), which greatly impacted the region. From the present point of view, the windstorm was a one-time extreme event, which is not to be confused with a long-term change in wind intensity. Yet people see a potential thread in the increase of wind, as the wind moves weather patterns and with them weather extremes. In contrast to this, a few study participants explicitly denied that the wind strength or frequency have remarkable changed in comparison to the past.

Another controversial theme concerned observed **changes in the intensity of storms**. In total 13 participants expressed their impression, that storms are becoming more intense, yet participants referred to different types of storms. An intensification of electrical storms, snowstorms and windstorms was mentioned. To acknowledge these numerous observations and to avoid a false classification, they are merged into the LICCI "Change in the intensity of storms (not further specified)".

As mentioned above, participants mentioned that it now gets warmer earlier in the year. This change was described by eight participants as **spring starting earlier**, as the increased temperature is made responsible for the temporal shift of other process which are characterising the season of spring for the local population (e.g. earlier sprouting of vegetation). Therefore, the earlier onset of spring was identified as a LICCI.

Another observation reported by four participants was that **the whole vegetation period has extended,** implying that there are more days were the temperatures are high enough to allow vegetational growth, without referring to a specific season. This matches some single observations, which described that autumn seems to last longer or that winter is starting later.

Table 7: List of observations of local climate change impacts on the climatic system (n=21).

Sub-system	**Element (number of LICCIs)**	**LICCI**	**Trend**	**Number of observers from SSI (+FGD) n= 18 (+ 12)**
Temperature	Seasonal Temperature (4)	Changes in (C.i.) the mean temperature in winter	increasing	10(+5)
		C.i. the mean temperature in summer	increasing	7 (+3)
		C.i. the mean temperature in spring	increasing	5 (+3)
		C.i. the mean temperature in autumn	increasing	5
	Mean Temperature (4)	C.i. mean temperature (not further specified)	increasing	3(+2)
		C.i. temperature associated with elevation	increasing	7(+3)
		C.i. the temperature during the night	increasing	7(+1)

		C.i. temperature fluctuations	increasing	3(+2)
	Temperature extremes (1)	C.i. the frequency of days with extreme temperatures	more frequent	6
	Sunshine (1)	C.i. sunshine intensity	more intense	3(+2)
Precipitation	Precipitation extremes (2)	C.i. the intensity / strength of heavy rainfall events C.i. the frequency of heavy rainfall events	more intense more frequent	10(+10)
	Precipitation distribution variability and predictability (2)	C.i. the temporal distribution of rainfall	longer periods without rainfall. Higher amounts of rain falling in shorter time periods.	2(+3)
		C.i. the predictability of rainfall	less predictable	8
	Seasonal precipitation (2)	C.i. in the amount of rainfall in spring	less	3(+1)
		C.i. in the amount of rainfall in summer	less	7(+1)
	Drought (1)	C.i. the intensity of drought	more intense	6(+1)
Air masses	Wind (2)	C.i. wind strength or speed	stronger	5(+1)
		C.i. the number of windy days	more	3(+1)
	Storm (1)	C.i. the intensity of storms (not further specified)	stronger	4(+9)
Seasona l events	Duration and timing of seasons (2)	C.i. the onset of spring	earlier	6(+3)
		C.i. the length of the vegetation period (spring to autumn)	longer	2(+2)

5.2.1.2. Physical system

<u>Cryosphere (Ice & Snow)</u>

Seven out of eleven LICCIs in the physical system (table 8) are changes in the cryosphere. This includes changes in the glaciers, in permafrost, in snowfall and snow cover and the occurrence of climate-induced hazards.

Three participants experienced a **change in the physical structure and texture of snow**. They described the snow to be softer and wetter than in the past. In former times, the snow used to be drier. Participants had the impression that nowadays there is more wet snow in the valley bottom, while powder snow became an exception. The main driver for this change is seen in the increase of the mean temperature in winter. With degrees below zero, the snow is drier, and precipitation falls in form of snow. With the higher temperatures the snow crystal themselves are thought to be “drier”, but it was also reported that it rains in higher altitudes and more frequently on the already present snow cover.

This is related over to the perception of six participants that **the snowline has been gradually rising** over the last years, meaning that it is raining instead of snowing in higher altitudes. This was especially remarked upon in regard to summer, where the snowline rose apparently up to 4800 m a.s.l., which hasn’t been the case 20 years earlier. Another participant stated that in the past it was snowing from 3000 m a.s.l on during summer and that it never used to rain on the Großglockner, while nowadays it does. This change was mainly attributed to the increase in temperature associated with elevation or the general increase in mean temperatures; Other participants additionally mentioned the higher mean temperature in summer and the increase of temperature during the night as a driver for this change.

Some participants related their observation that there is less snow cover and a **shorter snow cover on the glacier during summer** (observed by six participants) to the rise of the snowline in summer. It is raining instead of snowing on the glacier. Even if there had been a lot of snowfall during winter, the higher mean temperatures in summer precipitate the melting of the snow cover. Also, the increase in temperature associated with elevation, the higher temperature during summer nights and the occurrence of intense heat waves during summer were mentioned as drivers.

Figure 4 View from Berger Kogel (Virgen) of the receding glaciers of the Venediger Group, above Prägraten (Fuchs, 2020)

The significant **retreat of the above ground glaciers** in the area around the Großglockner and the Großvenediger was one of the most often mentioned LICCI of this study (eleven observers) (figure 4). A participant in Kals described for example a retreat of about 40 m in the last 40 years (thus approx. 1 m/year) in an altitude of 3000 m a.s.l.. Some observers share the impression that the melting of aboveground glaciers advances faster in the past 20 years. People clearly see the decreased snow cover on the glacier during summer as crucial driver: The snow protects the glacier from rainfall and reflects the sunlight, two factors that promote the melting. It requires approx. 10-15 m of snow to develop one meter of ice over several decades. But nowadays the ablation zone was observed to outweigh the accumulation zone of the glacier. The higher mean temperature in general and in summer, as well as the more intense sunshine were also interpreted as direct drivers of the glacial melting.

Another change that was mainly identified and described by the impacts that the seven observers attribute to it, was the advancing **permafrost degradation**. Its visible evidence is for example the increase of rockfall and rock failure (see Soil & Land). The increase of temperature with elevation/ the rising zero-degree line is clearly understood as the driver of this change.

Also, the **average amount/depth of snow in winter** was perceived by ten participants to have reduced in comparison to the past. Many participants recounted their childhood memories, where the snow has reached up to their knees or that they had to dug free their way to get to school. They reported that once it started to snow and a snow cover had formed, the snow cover usually stayed closed over the rest of the winter, while nowadays this is seldomly the case. Despite the agreement on the change itself, opinions on what the drivers are diverged a lot. People mentioned changes in the timing or the frequency of the snowfalls, changes in the snow amount per snowfall or changes is how fast the snow is melting again. One theory is, that as the snow is softer and wetter and it rains more often in winter, the snow cover gets more compacted and therefore seems lower. Through the interviews and FGD no clear trend of which are the definite drivers could be identified. Yet, most participants mentioned the temperature increase in winter as a crucial cause for the reduction in the snow amount.

Another pattern that shows up in the collected observations of snow, concerns the **temporal distribution of snowfall**. Seven participants shared the impression that, like the rainfall, it snows less continuously than in the past. It seems to them that it snows less frequently, but when it snows, it can happen that it snows a lot in a short period of time. For this reason, the snowfall seems to them less predictable than in the past. While participants did not mention any drivers for this variability in snowfall, they gave detailed descriptions of three snowfall events with high precipitation in short time, which occurred in the winters in 2018/2019, 2019/2020 and 2020/2021.

These events are described by the participants as **extreme snowfall events**, as the amounts of snow were larger than they had been for decades and in some cases caused great damage. As the events have only taken place in the last three consecutive years, no long-term trend can be assumed. Therefore, they are not classified as LICCI. Nevertheless, they are described here because the participants link their causes and impacts to climate change driven changes. The participants assume that the higher temperatures in winter cause the air to absorb more water, which then precipitates as heavy snowfall when/where temperatures decrease. Whether and when this happens, however, depends on the respective weather conditions/currents. The participants agree that the weather currents from the South bring the extreme snowfalls (e.g. Genoa low from Italy), as has been the case in the last three winters. In addition, some participants believe that the warmer temperatures and the resulting change in snow quality (wetter, softer, heavier), exacerbate the impact of the large amounts of snow (e.g. forest damage).

Soil & Land

One LICCI within the terrestrial physical system (Soil & Land) was mentioned. Twelve participants observed that **the soil freezes less often or only for shorter periods during winter**. They attributed this development to the increase in the average temperature in autumn and winter. They thought it was also decisive whether the soil is already frozen before it is covered by snow, because the snow has an isolating effect, which hampers soil temperatures to drop under 0°C.

Climate-induced hazards

Three observed changes were identified as climate-related hazardous events or trends.

There have been different observations saying that the frequency and size of avalanches have changed, however no common trend could validate these observations. The only observation that was confirmed by several – four - participants, was that the **type of avalanches** has changed over the last years. Thirty to 20 years ago wet snow avalanches were secondary - more dry avalanches descended and menaced the exposed villages (for most Prägraten and Kals) - while nowadays wet snow avalanches are more frequent than dry avalanches. This change was associated with the wetter, softer and heavier snow caused by the increase in temperature. On the one hand this trend was valued as positive because the dry snow avalanches have a bigger range and were estimated to be more dangerous for humans The wet snow avalanches, on the other hand, may cause more property damage.

The most frequently observed hazardous trend (seven observers) concerned the **increase in rockfall and rock failure events in the mountains**. As mentioned earlier, this was considered to be caused by the advancing degradation of permafrost, as well as the retreat of glacier which is exposing loose material/stones/boulders. Such events have already done damage to persons and pose a risk for mountain tours/hikes in certain areas.

Furthermore, seven participants reported that during heavy rainfall events or electrical storms, it can happen that it hails on the glacier. When this is the case, the risk of **dynamic flooding and landslides** is very high. This is especially true when the glacier is not snow covered, since the snow would absorb the water and slow down the run-off. Such dynamic flooding and landslides are reported to occur more frequently than in the past, causing property, forest and personal damage.

Table 8: List of observations of local climate change impacts on the physical system (n=11).

Sub-system	Element (number of LICCIs)	LICCI	Trend	Number of observers from SSI (+FGD) n= 18 (+ 12)	Level of agreement during FGD
Snow & Ice	Glacier (1)	Changes in (C.i.) the extension of glaciers	Reducing	7(+4)	Not discussed (Nd)
	Permafrost (1)	C.i. the thawing or melting of permafrost	Increased thawing/melting	4(+3)	Nd
	Snowfall and snow cover (5)	C.i. the physical texture and structure of snow	Wetter, softer, heavier snow	(+3)	Nd
		C.i. the spatial distribution of snowfall	Rising snowline	2(+4)	Fully agreed
		C.i. the length/duration of temporary snow cover	Shorter snow cover on the glacier during summer	2(+4)	Nd
		C.i. the amount of snowfall	Reducing average snow amount	8(+2)	Partly agreed
		C.i. the temporal distribution of snowfall	Longer periods without snowfall. Higher amounts of snow falling in shorter time periods.	7	Nd
Soil & Land	Soil temperature (1)	C.i. soil temper ature	Increasing; less/shorter freezing of soil	5(+7)	Fully agreed
Climate-induced hazards	Avalanches (1)	C.i. the type of avalanches	More wet snow avalanches, less dry avalanches	(+4)	Nd
	Rockfall (1)	C.i. the frequency of rockfalls	More frequent	5(+2)	Nd
	Dynamic flooding (1)	C.i. the frequency of dynamic flooding	More frequent	3(+4)	Partly agreed

5.2.1.3. Biological system

Three LICCIs on the biological systems were reported (table 9), including one change in the terrestrial wild flora and two in the terrestrial wild fauna.

Terrestrial Wild Flora

The first one concerns the phenology of wild plant species. Ten participants have observed different **wild plant species to sprout and flower earlier in spring** than they used to. This concerned fruit trees (see human system) but also single observations of different wild plant species: edelweiss (*Leontopodium nivale*) flower up to half a month earlier; alpine pasqueflower (*Pulsatilla alpina*) grow and flower progressively earlier in the last 30-40 years;

larches (*Larix decidua*) start to sprout earlier (already in May) more often; blueberries (Vaccinium myrtillus) flower up to one month earlier; palm willow (*Salix caprea*) and elder (*Sambucus spp*.) flower earlier. The observers agree that the timing of the plants depends on the temperature profile over the year. The trend that the plants sprout/flower earlier was thus associated to the higher mean temperatures in spring, the earlier onset of spring or the longer vegetation period in general.

Different **wild plant species have been observed by six participants to grow in higher altitudes** than before. For example, edelweiss (*Leontopodium nivale*) have been reported to grow almost exclusively from altitudes of 2000 m a.s.l. on, while in former times (approx. 50 years ago) they could be found at 1800 m a.s.l.. It was also mentioned that there seems to be a higher abundance of plants growing in high altitudes (around 3000 m a.s.l.), e.g. certain gentian species (*Gentiana spp*.) or glacier crowfoot (*Ranunculus glacialis*). Closer to the valley bottom, people have observed common hazel bushes (*Corylus avellana*), black and/or red-berried elder (*Sambucus nigra*/*Sambucus racemosa*) and rowan (*Sorbus aucuparia*) to rise to higher altitudes. The upward trend was associated with the increase in temperature associated with elevation. Higher areas become habitable, while lower areas might become unhabitable due to temperatures being too high (see e.g. edelweiss). Yet, most of the participants of the FGD could not confirm such changes. Therefore this change was not defined as LICCI.

<u>Terrestrial Wild Fauna</u>

Changes in the abundance of birds: There have been several different observations of change regarding birdlife. However, only two clear trends could be determined and only one of them was certainly attributed to climate change: four participants observed that the abundance of magpies (*Pica pica*) increased, particularly remarkable since 2 to 3 years. It was explained that magpies used to leave the area during winter as the conditions were not habitable for them. Due to the milder conditions in winter, they started to overwinter on site, which explains their higher abundance. The magpies have been considered to displace other birds (e.g. thrushes), as they are nest predators. Also, they have been blamed to feed on fruits of the cherry trees.

Eight participants also observed that **the incidence of ticks has increased**. The observers explained that there used to be no to hardly any ticks at this altitude. Today, they regularly find ticks on the udders of cows or on their own bodies. They attribute this increase to the more favorable climatic conditions for ticks caused by the increased mean temperature in general and the increase in temperature associated with elevation.

Table 9: List of observations of local climate change impacts on the biological system (n=3)

Sub-system	Element (number of LICCIs)	LICCI	Trend	Number of observers from SSI (+FGD) n= 18 (+ 12)	Level of agreement during FGD
Terrestrial Wild Flora	Wild flora phenology (1)	Changes in (C.i.) wild plant species flowering time (plants-shrubs-trees)	Sprouting and flowering earlier	7(+3)	Partly agreed
Terrestrial Wild Fauna	Terrestrial fauna abundance (2)	C.i. the abundance of birds	More magpies	2(+2)	Partly agreed
		C.i. the abundance of insects	More ticks	8	Not discussed

5.2.1.4. Human system

Six LICCIs on the human system have been identified. Most of these observed changes are agricultural related – three in pastures and grasslands, one in the cultivation of crops -, the remaining two changes concern infrastructure (table 10).

Pastures and Grasslands

Seven participants observed that, both at the valley bottoms, as well as on the mountain pastures and meadows, **the vegetation starts to grow earlier**. People stated that there were years were the grass started to grow two to three weeks earlier than in former times. Many observers stress that the vegetational growth can differ from year to year depending on the annual weather conditions, yet they see a trend which is attributed to the increased mean temperature in spring/ the earlier onset of spring. Participants mention that even if there was a lot of snow in winter, the spring season and with it the vegetation period starts earlier (also in mountain meadows/pastures), because the snow is also melting faster. This again was related to the higher mean temperatures and the more intense sunshine.

Although the vegetation period and with it the vegetation growth in pastures and meadows starts earlier, nine participants observed that the **total pasture productivity has decreased** over the last years. Many participants recounted that in the last years the hay yields of at least one of two cuts was often lower than in the past. This partly resulted in fodder shortage for livestock. The increasing drought/dry spells in spring and summer, in combination with the higher mean temperatures and the occasional heat waves in summer, are thought to hamper the vegetational growth. People explained that the constant and even rainfall used to keep the soil moist in the past. With the heavy rainfall events that bring a lot of precipitation in short time, the soil is not capable to take up all the water, thus a great part runs off without serving as a resource for vegetational growth. Infiltration is meant to be additionally hampered if the soil is dried out after longer periods without rainfall.

Besides the drought, also the **June beetles (*Amphimallon solstitiale*)** have been observed by ten participants to **increasingly damage the grassland**. The larvae of the June beetle overwinter in the soil, feed on the roots of the vegetation and thus damage the turf. Observers described how they could completely remove parts of the grass sward on infested fields. They also have the impression that the infestation is stronger on grassland which is already suffering from drought and heat. In contrast to their larvae, the adult June beetles are more and more a problem for fruit trees/orchards. The beetles feed on still unripe and ripe fruits, as well as on the leaves. So, the fruit yield gets affected, but also the growth progress of the trees was mentioned to be reduced. The increase in June beetles was attributed to the fact that temperatures rarely fall below 0°C in winter, so the ground freezes less often. This makes it easier for the beetle larvae to overwinter. Since the June beetle prefers a warm climate, the participants suspected that the higher average temperatures facilitate/accelerate its reproduction. Some participants had the impression that the common cockchafer (*Melolontha melolontha*) has also increased, having similar negative impacts on the grassland. However, most participants disagreed with this. They said that common cockchafers only occur at lower altitudes (e.g. Lienz, Matrei), but at this altitude they hardly occur, respectively do not yet pose a problem.

Cultivated plant spp. (crops, orchards)

The observation that some wild plants **tend to sprout and flower earlier** also accounts for the **crop plant species** and was mentioned by four participants. It was mainly observed that fruit trees (most notably cherry and apricot trees) sprout and flower earlier in the year. But also, shrubs like redcurrant (*Ribes rubrum*) have been observed to flower up to one month earlier than they used to do. As with their wild relatives, this time shift was attributed to the higher mean temperatures in spring, the earlier onset of spring or the longer vegetation period in general.

Infrastructure

Concerning the infrastructure, five participants mentioned **increasing damages in the hiking/mountain path network** due to heavy rainfall and storm events. This change was highlighted, because the hiking path network is seen as a central element of the local tourism, which is an essential source of income for all three communities. As for higher altitudes it was also reported by five participants that **several mountain tours are no longer accessible** or that **routes had to be changed**, because they became too dangerous. This is due to the retreating glacier – leaving behind scree fields/areas which are harder or impossible to cross - and the degradation of permafrost, both causing unexpected rockfall.

Table 10: List of observations of local climate change impacts on the human system (n=6).

Sub-system	Element (number of LICCIs)	LICCI	Trend	Number of observers from SSI (+FGD) n= 18 (+ 12)	Level of agreement during FGD
Pasture & Grassland	Pasture availability and productivity (1)	Change in (C.i.) pasture productivity	decreased	7(+2)	Not discussed (Nd)
	Pasture phenology and reproduction (1)	C.i. pasture species' timing of vegetative growth	earlier	7	Nd
	Pasture disease/pest/mortality (1)	C.i. the frequency of "pests" in pasture species	More frequent	6(+4)	Partly agreed
Cultivated plant spp. (crops, orchards)	Cultivated spp. Phenology and reproduction (1)	C.i. crop flowering time	earlier	3(+1)	Partly agreed
Infrastructure	Mountain path networks (2)	Damage of hiking paths	increased	3(+2)	Partly agreed
		Closure or relocation of mountain tours	Increased	3(+2)	Partly agreed

5.2.2. Local observations of partially climate-driven changes

Ten observations described environmental changes impacting the biological and the human system, which were (a) attributed both to climate change and to not climate change related drivers or (b) where the participants could not agree on the cause of the change (i.e. whether the change was climate change or not climate change driven) (table 11).

5.2.2.1. Vegetational growth/Cultural landscape

One of the most frequently addressed observation of change in the biological system (eighteen observers) was **the rise of the tree line**. First, most participants clarified that centuries ago, the natural tree line used to be higher than it is now, but that it has been lowered by humans through management (deforestation, grazing etc.). Some participants stated that trees are now regrowing/ taking back the area between the "artificial" and the natural tree line. This rise is attributed to the reduction or abandonment of management (i.e. grazing, mowing, logging, cutting and burning of dwarf shrubs etc.) in these altitudes. Nevertheless, several participants also observed that trees started to grow in areas which have never (as far as participants can remember) or rarely been managed. Young trees have also been found to grow in altitudes

Figure 5 Young larches grow in alpine pastures near the timberline, Virgen (Fuchs, 2020)

above the natural tree line (figure 5). They therefore think that the tree line is not only rising because of the abandonment/reduction of management, but also due to climatic changes: they identified the increase in mean temperature and in temperature associated with elevation, as the main drivers. They also added the prolongation of the vegetation period as a driver. Claims of how much the tree line has exactly changed, varies from participant to participant as they observed this change at different local spots, which are differently impacted from management. Yet, they agreed that mainly *Larix decidua* was found to grow in higher altitudes than before. In some spots in Kals, also *Pinus cembra* was observed to mount.

Besides the increased growth in altitude, four participants reported a **general increase in vegetation productivity**. Participants mentioned a higher wood increment of trees (e.g. *Picea abies* has longer new shoots, than in the past) or that certain plant species seemed to be lusher and to grow better than before. They believe that this is related to a general increase temperature and that this trend can be limited by a lack of precipitation. Regarding the forest, though, participants assumed that also the change in forest management over the last centuries were influencing its productivity and that it was thus difficult to be sure how big the climate change influence really is. In the past the forest was used more, serving as wood pasture for the farm animals and as source for timber and firewood. Thus, the trees growth increase was considered to be reduced/hampered in comparison to today.

The observation reported by sixteen participants that **scrub encroachment is advancing in mountain pastures and meadows** is in line with the above-mentioned observation that the trees are reclaiming their former habitat. Land which is less or no longer managed (i.e. grazing, mowing, logging, cutting and burning of dwarf shrubs etc.) becomes overgrown by dwarf shrubs (e.g. black alder (*alnus glutniosa*), alpine roses (*rhododendron ferruginosum/hirsutum*), dwarf juniper (*Juniperus communis alpina*); Grün-Erle (*Alnus alnobetula*)) and (subsequently) trees (i.e. small *larix decidua* and/or *pinus cembra*). Without management an area is densely overgrown within a few decades. For most participants this change is exclusively land management and not climate change driven. Participants explain this development through the decline of people working in agriculture nowadays. In former times there were ten or more people per household/farm helping to manage the land. There always used to be somebody who stayed on the alp the whole summertime and took care of the pasture/meadow maintenance (e.g. cutting dwarf shrubs, mowing, herding). Nowadays this is rarely done, as family labour force is missing and employing somebody would be too expensive. Also, in former times the animal species grazing on the alpine pastures were more divers (e.g. goats, sheep, cows, horses), which is assumed to have kept the pastures free from woody plants more efficiently, as the different species are specialised on feeding on different plant types. Besides, in the past animals were rather herded - which meant that they could be guided to specific places/spots to keep them free from shrubs etc. - while nowadays they are mainly kept in fenced paddocks. Doing alpine agriculture in the "old way" became unprofitable. However, some participants think, that also climate change matters in this context, as the increasing temperatures are assumed to foster vegetational growth. Thus, they belief that climate change is advancing the scrub encroachment and forest development on abandoned/marginally managed land.

Participants described several impacts of the scrub encroachment: From an agricultural perspective, grazing area/fodder for livestock gets lost, although, due to the increasing temperatures, the additional fodder resources of the alpine pastures/meadows would be more and more needed. Also, overgrown areas lose their legal status as alpine pasture, consequently farmer get less subsidies and are only allowed fewer animals on the alpine pasture during summer. From an ecological perspective, the soil erosion is increasing with the replacement of pasture vegetation with dwarf shrubs. This is accompanied by the decrease in biodiversity – dwarf shrubs displace/outcompete herbaceous flowering plants. Also, the risk descending avalanches should be increasing, as the snow slides more easily on unmanaged (no grazing or mowing) land with long gras.

5.2.2.2. Invasive species

Another pasture and grassland related observation mentioned by five participants, is that **the abundance/domination of certain weeds has increased**. This counts for different species in different habitats. For example, European white hellebore (*Veratrum album*) and species of the genus *Adenostyles* (*A. alliariae* or *alpine*) were mentioned to be more dominant in alpine pastures/meadows today. As *veratrum album* is poisonous, it presents a danger for grazing animals. Its increase was associated with the decrease in weed management compared to the past. The *Adenostyles* specie was considered as invasive but not problematic and its increase was attributed to the higher temperatures. People also observed other plant species considered as “weeds” to be more invasive in the last years. In meadows/ pastures on the valley bottom more nitrophilous and/or deep-rooting plant species (e.g. dock (*Rumex spp.*), common hogweed (*Heracleum sphondylium*), caraway (*Carum carvi*) are observed to be growing. Participants reasoned that with the changes in grassland management: e.g. increased exploitation – cutting more frequently/grazing with higher stocking density; less manual weeding (e.g. “Ampferstechen”); use of heavy machinery; increased fertilization due to farm external nutrient input through additional fodder purchase (e.g. straw and concentrate), because of increase in livestock, due to the change from mixed farming systems to mainly only livestock farming systems. Other grassland weeds (no specific species named) are thought to be introduced with imported resources (e.g. straw). Again, some participants also assume a climatic influence: deep-rooting plants may dominate, as they are better adapted to the drier condition caused by climate change. Several participants mentioned a lower fodder quality for livestock as a consequence of the increase in certain deep-rooting weeds with a low feed value.

Besides grassland weeds, in Virgen also the **distribution of invasive alien plant species** has been observed by three participants. It was reported that *Fallopia japonica, Solidago canadensis, Impatiens glandulifera* and *Heracleum giganteum* occur in Virgen. Originally introduced anthropogenically (e.g. *Heracleum giganteum* as honey plant), the invasive alien species now seem to be spreading. Part of the participants do neither think that the spreading can be distinctly related to climate change, nor do they perceive that the distribution has increased significantly. In their opinion, invasive alien species do not yet pose a problem compared to lower regions with longer vegetation periods. However, other participants think that the increase in temperatures must have especially favoured the distribution of *Heracleum giganteum*, which spread along different streams and are considered harmful (i.e. phototoxic plant).

5.2.2.3. Forest health

Participants stated that overall, the local forests were in good condition (e.g. suitable mixed forest for this altitude, no monocultures of *picea abies,* no overexploitation). Yet, several participants mentioned that the forest seemed to be more vulnerable/less resilient/more weakened during the last years. Reason for such statements were the observations that the forest has been strongly damaged by storm-, snowfall- and drought events, as well as that the incidence of certain pests and disease (e.g. larch leaf-miner (*Coleophora laricella*), needle bladder rust (*Chrysomyxa rhododendri*)) has increased. These changes are perceived as being partly interdependent and driven by climate change and changes in forest management.

Ten participants described an increasing mortality of trees in the local forests during the last years. The **increase in severity/frequency of windthrow, windsnap and snow-break and the related augmentation of storm-damaged timber** was ascribed to the increase in heavy snowfall and wind intensity, as well as to an increase in drought, which is assumed to weaken the trees and make them more susceptible to physical damage. Besides that, several changes in forest management were mentioned to be influential. Some privately-owned parts of the forests are rarely managed and thus overaged, which makes them more prone to physical damage. Participants emphasize that, as for the abandonment/decrease of alpine pasture utilization, this is due to the decrease in labour power. In former times the forest was managed by the people who owned it: timber/firewood was cut for personal use, livestock grazed in the forest, work was done manually and with animal power. Nowadays most of the locally used timber does not originate from the local forests, but is bought in. For many forest owners it is no longer profitable to manage their parcel as labour power, time, money etc. are lacking. Some forest parcels are difficult to access, which is why professionals with special machinery have to be hired to manage them. While this is expensive, the wood price is generally low. Compared to the past, in contemporary forest management trees are planted narrower, which inhibits their development of a strong rooting systems, and thus makes them less wind/snow resistant. Furthermore, they are planted in rows, which, during wind/snowstorms, can lead to a "domino effect", where trees collapse over a wider area. Such events (e.g. storm "Vaia") cause an oversupply with timber, which can lower the price of wood even further.

Weak rooting systems also lower trees' capacity to take up water and thus their resistance to drought stress. Consequently, trees produce less resin, which is usually part of their natural protection against pests – e.g. bark beetles. Trees which suffer from drought are more prone to bark beetle infestation. As it has been observed by six participants that **the bark beetle infestations** (subfamily: *Scolytinae*) **have increased** over the last years, this was therefore linked to more frequent/intense drought events as well as to lower drought resistance due to changes in the forest management. Mainly *picea abies* (and rarely *larix decidua*) were reported to be affected by drought and bark beetles. Also, the high amount of storm-damaged timber originating from windthrow/windsnap and snow-break, have been blamed to cause an increase in bark beetle infestation. Independent of forest health, it was also assumed that the bark beetles can reproduce faster and inhabit higher regions due to the increasing mean temperatures. Also, they are expected to overwinter in the bark of infested trees/in the soil more easily due to the less frequent freezing events in winter.

5.2.2.4. Game

Three participants observed that **alpine ibex (*Capra ibex*) became increasingly infected with mange** in the last years. Participants described mange as a disease being transmitted by parasitic mites, which is breaking out in waves about every 13-15 years and is capable of infecting and killing a large number of animals within 1-2 years. Participants in Kals thought it was difficult to ascertain whether alpine ibex is now especially affected by mange, as they have only been reintroduced to the eastern Tyrolian part of the Hohe Tauern National Park about 45 years ago. Yet they agree that alpine ibex could be more susceptible to the disease than other game species because they live in herds, which facilitates the disease's transmission. Participants from the other two communities also assumed that more mange cases occur because the alpine ibex density has increased, which again is due to the decline in game hunting activity over the last years. It was also mentioned, that in comparison to the past, game is being increasingly disturb by humans, as the radius of sport and tourism activities has expanded. This is particularly problematic when people invade in the resting zones of wild animals in winter. These disturbances have negative impacts on the health of game populations and are therefore also understood to play a role in the increase of mange infections in ibex.

Some participants also emphasized that alpine ibex does generally not cope well with heat: "*it has to do with the change of hair. They don't lose their winter hair in that sense, but in the winter their summer hair actually grows through. And in the cold, they know how to shed it, but when it's too warm, it's like a heat build-up [...] and they suffer extremely from it*." Thus, the warmer it gets, the more heat stress they experience. This weakens their immune system while favouring the disease/ the mite. Additionally, the transmission of the disease might be facilitated as the ibex's territory gets limited to cooler regions and thus the animal density increases in these areas. So possibly there is a connection between the spread of mange in alpine ibex and the increasing temperatures due to climate change. To proof this statement though, the participants thought it would be necessary to observe the development over a longer period of time.

Eight participants made another observation concerning game. They reported that **the red deer (*Cervus elaphus*) population has strongly increased** in the past years. Several reasons given for this are related to changes in hunting/wildlife management: the animals are not hunted enough because, on the one hand there are fewer and fewer full-time hunters/free time hunters have less time and on the other hand because it is challenging to hunt red deer. If hunted incorrectly, red deer only come out at night, which makes hunting even more difficult. As a result, shooting plans can at times not be fulfilled and so the population increases. Also, the increased feeding of game in winter was meant to facilitate the survival of more individuals over winter. It was also suspected that the increasing bush encroachment in the alpine pasture area gives the wild animals more opportunities to hide, which makes hunting more difficult. Few participants also see a climate change connection in the increase of the red deer population. They think that due to warmer winters with less snow, the animals find enough fodder and can hibernate more easily.

Participants also mentioned some further impacts of the increase of red deer: More red deer also means more damage in the forest. And if there is as much precipitation as there was in the last winter, the deer will not find any grazing and will cause even more damage to the trees. To prevent the damage caused by deer depredation, it is therefore necessary to feed the animals during the winter. But if the feeding times become longer than in the barn in agriculture, then there is no longer any point. Besides, most of the local forest is protection forest, thus too much "shelling damage" (Schälschäden) is not tolerable here.

5.2.2.5. Honeybees

Concerning the honeybees - the bee species usually kept here is a*pis mellifera carnica* - one trend, observed by six people, could be identified among most of the related observations: the **honey yields have been decreasing** over the last years. A participant recounted for example that in the 1970ties the highest honey yields in Kals were at approx. 40 kilos/beehive, while nowadays 20 kilos/beehive are already good and that in the last years the average was around 10 kilos/beehive. Similar numbers were mentioned for Prägraten. The participants explained that this could be due to many different factors and that it was difficult to determine whether certain factors are more decisive than others. Besides general factors like the bee breed and the vitality of the bee colonies, also the yearly weather conditions, the varroa mite (*Varroa destructor*) and the biodiversity have been mentioned.

As for the weather condition, especially the temperatures in spring and the occurrence of drought are influential. Some participant observed that the bees start to swarm earlier in the year due to the earlier onset of spring/the higher temperatures in spring (associated: earlier blossoming). If frosts occur later in the spring, the resulting lack of food for the already swarming bees can be problematic: bees feed on their stocked food resources, which results in lower honey yields, weakened bee colonies and more susceptibility for diseases and robbery. Also, hot and dry summers are thought to impact the bee's productivity: flowers wither faster, and plants invest in vegetative reproduction instead of generative. This means less nectar for the bees. More extreme heat days can cause that bees to mainly search for water to cool the beehives instead of collecting nectar. Less nectar signifies lower honey yields. Yet, all these observations to lower altitudes, as in higher altitudes it is still colder and the vegetation period starts later.

Furthermore, the varroa mite has caused many problems and led to a higher bee mortality. Two apiculturists thought that the mite might be favoured by the increasingly drier and warmer weather conditions, as this resembles more and more the climate of the mite's origin. Due to the warmer winter, the brood pause of the varroa mites gets shorter, thus more reproduction cycles might be possible.

The decreasing honey yields were also interpreted as a symptom of the general loss of biodiversity. Drivers of and other species affected by biodiversity loss: see chapter 5.2.3. Local observations of non-climate driven changes.

Table 11: List of observations of climate change and not climate change driven environmental change (n=10).

Subsystem	Element (number of LICCIs)	LICCI	Trend	Not climate change related drivers	Climate change related drivers	Number of observers from SSI (+FGD) n= 18 (+ 12)	Level of agreement in FGD
Terrestrial wild flora	Distribution (fungi-plants-shrubs-trees) (1)	Change in (C.i.) the distribution of wild plant species	Growing in higher altitudes	Changes/ reduction/ abandonment of mountain forest and alpine pasture management	Increasing mean temp.; increasing temp. with elevation; longer vegetation period	9 (+9)	Fully agreed
	Productivity and Quality (1)	C.i. the productivity of wild plant species (without further specification)	Increasing	Changes in forest management	Increasing mean temp.	4	Not discussed (Nd)
	Disease/pest/mortality (fungi-plants-shrubs-trees) (2)	C.i. the occurrence of pests in wild flora	Increasing	Changes in forest management	Increasing intensity of drought, storms and wind; increasing mean temp. in winter and in general; increasing occurrence of tree pests (e.g. bark beetle)	2(+4)	Fully agreed
		C.i. wild plant species mortality	Increasing	Changes in forest management	Increasing intensity of drought, storms, wind and single snowfall events	4(+6)	Fully agreed
	Invasive alien Species (fungi-plants-shrubs-trees) (1)	C.i. the distribution of wild plant species stated as invasive	greater	Consciously and unconsciously by humans (e.g. honey plants, machinery); distribution via wind, water etc.	Increasing mean temp.	3	Nd

Terrestrial Wild Fauna	Disease/pest/mortality (1)	C.i. the frequency of diseases (i.e. mange) in terrestrial fauna (i.e. alpine ibex)	Increasing	Increasing perturbation of game by humans (e.g. sports, tourism); Decline in game hunting, thus higher *alpine ibex* density	Increasing mean temp. in summer and in general	3(+1)	Partly agreed
	Abundance of terrestrial wild fauna (1)	C.i. the abundance of terrestrial fauna (i.e. red deer)	increasing	Changes in hunting/wildlife management	Increasing mean temp. in winter; Reducing amount of snowfall; increasing scrub encroachment in alpine pastures	3(+5)	Nd
Land cover change & land degradation	Habitat/Landscape/ Ecosystem (1)	C.i. land cover (i.e. scrub encroachment of alpine pastures/meadows)	increasing	Reduction/ abandonment of alpine pasture and meadow management	Increasing mean temp.; increasing productivity of wild plant species	7(+9)	Fully agreed
Pastures and grasslands	Pasture spp. composition, distribution and quality (1)	C.i. the abundance of specific pasture species	increasing	Changes in grassland management	Increasing mean temp. (*Adenostyles*) and intensity of drought (more deep-rooting herbaceous species)	5	Nd
Livestock	Livestock productivity and quality (1)	C.i. livestock productivity (i.e. honey)	decreasing	Decreasing biodiversity; Pests (i.e. varroa mite)	Earlier onset of spring; Increasing mean temp. in spring and winter; more frequent heat days	2(+4)	Fully agreed

5.2.3. Local observations of non-climate driven changes

In total six of the observed environmental changes have been identified by the study participants as not being climate change driven (table 12). Five of these changes are impacting the biological and one the human system, while none affect the physical system or the climatic system.

A general loss of biodiversity has been described by five participants as driver or consequence of change in several contexts (e.g. result of scrub encroachment; driver of decreasing honey yields). More specific descriptions of biodiversity reduction/loss mainly concerned the reduction in plant and partly in insect diversity.

In total six participants representing all three communities shared the perception that **plant diversity in managed meadows and pastures** has decreased in the last years. For example, they stated that there are less meadows where it was possible to pick a beautiful bouquet of flowers. All observers agree that this is due to changes in grassland management. Some areas are being overfertilized and more slurry instead of (solid) manure is used for fertilization. Thus, the meadows/pastures are reported to be dominated by nitrogen-loving plant species (e.g. *Heracleum sphondylium, Rumex spp.*), but for example fewer Alpine marguerite (*Leucanthemopsis alpine*), wood pinks (*Dianthus sylvestris*) or species of genus *Campanula* (bellfowers) and the genus *Hypercium* are growing. Also, the meadows are often overutilized, as they are cut too often (more than 2 times) and/or too early. Thus, many plant species cannot blossom, or mature, or self-seed and the diversity reduces. One main reason for this change in grassland management is, that some farmers have more livestock than before, which is why they need more fodder and thus manged their land more intensively. Also, in private gardens and community owned green spaces the trend was to mow and weed the lawn and cut shrubs a lot. Yet there seems to be more awareness again and, for example, flowering stripes are being left for the bees.

In alpine pastures and meadows, the plant diversity decreases for the opposite reason: reduction or abandonment of management. As described in chapter 5.2.2. the shrub encroachment a replacement of a high diversity of herbaceous plants species by dwarf shrubs and subsequently trees. In this case the loss of plant diversity is thus linked to reduction/stop of activities like mowing, grazing, cutting and burning shrubs.

Directly related to the reduction in plant diversity is the perception that the abundance of certain insect species is reducing. Besides the honeybees (see chapter 5.2.2.), also the butterflies were considered to suffer from the less divers offer of flowering plants. A participant in Kals mentioned for example that in former time one saw more butterflies flying around and that certain species (e.g. *Arctia caja*) seem to have become rare. Also, the diversity of bumblebees (genus *Bombus*) and Grasheuschrecken was mentioned to have reduced. This statement though was based on scientific studies rather than on personal observations.

As for the **abundance of birds**, many different single observations have been made, which could not be confirmed by others and/or of which the driver was unknow. While some participants had the perception that there were generally less birds than in the past, others did not have this impression. Yet, a **decreasing trend in barn swallows** (*Hirundo rustica*) and **common house martins** (*Delichon urbicum*) was observed by eight participants. Most participants think this is due to changes of the habitat: it has become more difficult to nest in stables due to new construction guidelines for stables; birds find less material to build their nest, because it is “too clean” (not enough mud) around the houses or because soil sealing (asphalt and concrete) has increased. Few participants also mentioned that there are in general less insects as fodder for birds, or that due to the hotter and drier conditions in summer and the loss of humid zones in meadows means that house martins cannot find enough material (humid clay etc.) to build nests.

In Kals and Prägraten, four participants mentioned that in comparison to the past there are **less/no hedges, shrubs, trees, or little dry-stone walls** that separate the fields and were considered typical elements of the local landscape. They were removed during the land consolidation procedure which took place in Kals and Prägraten since the 1960ties, therefore more hedges etc. have been left standing. No land consolidation took place in Virgen, where hedges, shrubs, treelines are thus still growing and thriving. Although participants mostly rated the land consolidation as facilitating the work with machinery, others also mentioned disadvantageous impacts of the removal of the hedges: less wind protection, disadvantages for the microclimate and soil climate, less habitat for insects and other wild animal species.

With the mechanization of agriculture also humid/wet parts of land have been drained, dry stone walls have been removed and additional roads/paths have been made to be better able to work with the machines. Again, this was reported to reduce the habitat for many species (e.g. frogs, weasels, adders) which can no longer find shelter and whose food chain gets disturbed and who subsequently disappear.

Table 12: List of observations of not climate change driven environmental change (n=5).

Sub-system	Element (number of LICCIs)	LICCI	Trend	Not climate change related drivers	Number of observers from SSI (+FGD) n= 18 (+ 12)	Level of agreement in FGD
Terrestrial wild fauna	Abundance of terrestrial wild fauna (2)	C.i. the abundance of insects (i.e. bees, bumblebees, grasshoppers, butterflies)	Decreasing	Less biodiversity (e.g. less diversity in grassland/alpine pasture plant species)	1(+2)	Not discussed (nd)
		C.i. the abundance of birds (i.e. barn swallows (*Hirundo rustica*) and common house martins (*Delichon urbicum*)	Decreasing	Changes in the habitat (e.g. soil sealing; lack of nesting sites)	3(+5)	Fully agreed
Land cover change & land degradation	Habitat/Landscape/Ecosystem (2)	C.i. biodiversity	Decreasing	Changes in land management	4(+1)	Partly agreed
		C.i. the availability of specific landscape elements	Decrease/ loss	Land consolidation; mechanization of agriculture	4	Nd
Pastures and grasslands	Pasture spp. composition, distribution and quality (1)	C.i. the abundance of specific pasture species.	Decreasing plant diversity	Changes in grassland management (e.g. overfertilization and overexploitation)	3(+3)	Partly agreed

5.2.4. Unvalidated local change observations

Some observations of changes which have been collected during the interviews and FGD lack more detailed information on the trend and/or driver. Yet they might be relevant starting points for further research and are thus listed below.

5.2.4.1. Terrestrial wild fauna

Chamois (*Rupicapra rupicapra*) are thought to start to rut earlier in their life cycle. One participant observed that they first rut when they are one year old and thus have their first offspring when they are 2 ½ years old. Forty years ago, it was the commonly agreed upon opinion that it was ok to hunt chamois under four years, as they do not yet have offspring. This shift was vaguely related to climate warming. Another participant observed that deer starts to rut earlier in the year. In former times they started to rut in August, now they are thought to start in June. This shift was related to the earlier forage availability, which might be linked to climate warming.

Some participants observed an increase of infections in *Rupicapra rupicapra, Capra ibex* with infectious keratoconjunctivitis (IKC). Two participants speculated that the transmitting vectors, flies could be favored by the milder climatic conditions, which facilitates the transmission of the disease. Others relate the increase of IKC rather to the increased game density and the general fitness of game populations.

Some participants also mentioned to have observed less wagtails and redtails, but on the contrary much more thrushes than in the past.

One participant reported that unusually few fish were found during a test fishing in Kals in 2020. Especially trout were few. This was then also confirmed district-wide. The related drivers are unclear. The participant wondered whether the temperature increase in water bodies and the increase in dynamic flooding negatively influenced the fish population.

5.2.4.2. Terrestrial wild flora

Several participants have observed the impacts of the needle bladder rust (*Chrysomyxa rhododendri*) and the larch leaf-miner (*Coleophora laricella*) in the local forests. Yet it could not be clearly manifested whether this pest and disease are occurring more frequently/severely and whether it related to climate change.

5.3. Adaptation to climate change impacts and barriers to adaptation

Different adaptation measures with which the local communities respond to the observed changes in the climatic, the physical, the biological, and human systems were documented. Only those adaptation measures which fully and partly target climate change driven changes are presented in the results. For several adaptation measures, barriers, which are thought to hamper the present or future implementation of adaptation were mentioned and are also presented below.

Beside specific adaptation/coping measures, also more general behaviour patterns/habits, which are either strengthening or weakening the adaptive capacity of the local communities regarding climate change, have been identified. For both modes of adaption, this study distinguishes between adaptations that were/are being implemented and adaptation which were partly implemented and ideas for adaptation.

5.3.1. Local adaptation to climate change impacts

In total, the 38 adaptation and coping measures to climate change impacts have been collected in the three communities. Twelve of these adaptations occur in the agricultural and silvicultural context, i.e. cultivation (grassland, orchards, forestry) (table 13) and 11 in the livestock sector (table 14). Further 15 adaptions are mainly related to the impacts of natural hazards on public and private property (table 15).

5.3.1.1. Crop, fodder and tree cultivation

Implemented

Timing of grassland management

Some farmers stated that it is possible to **mow and harvest the hay up to half a month earlier** in the year, due to the earlier start of vegetative growth in meadows and pastures. Others agree that it would be possible to mow/hay earlier, but that the actual implementation depends more on the respective grassland management ideology of each farmer than on the climatic conditions. On favorable meadows (flat, sunny but not too dry) it became possible to cut three times per season, which was unimaginable 40-50 years ago (locally common management: two-cut system). But again, this is strongly linked to the general change in grassland management, as for example, the meadows are more intensely fertilized than in the past and it is more common to conserve the last cut as silo.

Fertilizer demand

Another long-term response to increasing drought and yield losses was the aim to **improve soil quality by building up humus**. Some farmers stated that they do so by **fertilizing with manure and composted manure**. Yet, many participants thought that the overall trend in fertilization management in the communities is opposed to this adaptation. The fertilization with slurry has increased a lot in the past and some areas are partly over-fertilized.

Water demand

In response to drought and yield losses **the irrigation of grassland has increased** within the last 5 years. Participants reported that mainly simple, self-made irrigation systems (e.g. old fire pump with water cannon; hose in stream) are being applied and that the irrigation water is taken from surface waters (i.e. streams) which are passing private and public land. Some farmers are said to have foresightedly installed junctions for irrigation, when the water pipes have been newly laid in Virgen. Besides grassland, also **home gardens and fruit trees** have been mentioned to be **irrigated more frequently** than in the past. One participant also mentioned that they were collecting rainwater from the roof for irrigation and that this might become a relevant measure in future times of water shortage.

Although many participants highlighted the positive effects of irrigation on hay yields, also numerous barriers were related in regard to this adaptation measure. Regarding the quality of irrigation water, several interviewees thought that the water from mountain streams and spring might be too cold to effectively foster vegetational growth. It might be required to prewarm the water before irrigation (e.g. running through sun collectors). Interviewees also questioned whether the composition of glacial water (e.g. high amount of glacial sediment) was suitable for the grassland vegetation, others stated that irrigation water must be of drinking water quality. Also, the technical aspects seemed challenging, as effective irrigation required more than only natural water pressure and a more sophisticated water supply system to reach more than just the fields surrounding a surface water. Such a technical improvement demands financial investment and bureaucratic effort, which are assumed to be too high, thus not worthwhile for many part-time farmers. Furthermore, many interviewees challenged the legality of extracting water from surface waters, especially when they are under nature protection (e.g. Isel as Global 2000 reserve). They stated that a fair distribution of water for irrigation demanded more organisational effort and that nature protection and water laws needed to be respected.

Seeding/Planting

The attempt to keep the vegetation cover in grassland closed through **regular re-sowing**, was also mentioned as an adaptive measure to prevent damages and yield losses due to increased drought. Also, the cockchafer grub is thought to be contained by **ploughing up and re-sowing infested areas**. This measure is implemented by individual farms and subsidised by the state of Tyrol. Yet, interviewees remarked, that ploughing-up was not viable on steep land, that subsidies only paid for the seeds but not for the extra work required and that re-seeding just provided more fodder for the cockchafer grubs.

Weeding & pesticide demand

To fight the cockchafer grub, some interviewees also stated that **chemically treated barley** was being applied. This method was criticised to be expensive and to demand specialized tools/machinery. Others reported that their chicken were effective in detecting and feeding on the pest (grub and adult stadium). Within an orchard, a participant is using beneficial organisms to fight the cockchafer.

To control weed resulting from changes in climate and grassland management, farmers have **different strategies for different invasive species**, ranging, for example, from earlier fertilization with manure and less fertilization with slurry (*Anthriscus sylvestris*), to later mowing (*Heracleum sphondylium*). One participant mentioned that *Veratrum album* needs to be cut in the rosette stage, which is the responsibility of the owners/tenants of the alpine pastures/meadows. As for the invasive alien species *Heracleum giganteum*, the municipality is continuously cutting the plant to prevent further spreading.

Partly implemented & ideas

Livelihood (sub) system

Participants thought that it could have become easier to **cultivate cereals**, due to the increasing mean temperatures and the longer vegetation period. Most participants stated that they are not or no longer cultivating cereals themselves, but they think that the climate is more favorable for cereals to reach maturity, in comparison to former times when cereals had to be harvested before being ripe. Some local farmers were reported to still cultivate or to have restarted to cultivate cereals. The agricultural mechanization was also thought to ease cereal cultivation, which used to be a very labor intense manual work in the past (harvest with the scythe, drying of cereals on "Harpfen" etc.). Some households/farms were also reported to have restarted to cultivate potatoes, mainly for self-consumption. Yet, participants were skeptical, whether there will be a long-term shift to more mixed farming systems. The required effort was thought to be higher than the financial profit. This would not be improved by the facts that the workload is already very high for most part-time farmers, that there is a general lack of workforce in agriculture, that an investment in specialized machinery would be needed and that part of the local area is too steep to be managed mechanically. Also increasing cultivation means that meadows and pasture would be reduced, which might lead to a feed/fodder competition, as mountain meadows are used less for hay production and the alpine pastures are becoming more overgrown/reduced. Three participants also expressed their concern, that if only few farmers restarted cereal cultivation, the cereal would be eaten up by the birds. Furthermore, it was remarked that marketing channels would be needed to sell the products at a worthwhile price.

Size, structure & composition

The higher mean temperatures and the longer vegetation period was also thought to be favorable for the growth and productivity of fruit trees. More people seem to **plant fruit trees** (Kals) or to try to cultivate crop species which are typical for warmer climate regions (e.g., lemon, figs, kiwi) (Virgen, Prägraten). One participant also thought that the **cultivation of wine**

and other thermophilic berry species could become more and more interesting with the progressing warming. Some participants also mentioned that a **greater variety of legumes** could be cultivated in home gardens due to the longer and warmer vegetation period, but that this depends on the eagerness to experiment of each person.

Infrastructure, construction & technology

Figure 6 View of Virgen's "Feldfluren" (Fuchs, 2020)

The so-called "*Virger Feldfluren*", which characterize the cultural landscape of Virgen, consist of **trees, hedges and dry-stonewalls separating individual fields** are thought to increase the adaptive capacity in regard to the increasing temperatures, drought and wind (figure 6)**.** One participant describes their origin: „ [..] *These are actually, for the most part, property borders, which were created [..] to make the land cultivable and to do grain farming. Then the stones were removed and [..] they were brought to the borders. And then the bushes grew on top of them*." [6] Some participants mentioned, the "*Feldfluren*" as good protection against the increasingly stronger wind, which, in combination with the higher temperature is desiccating the grassland. Also, they were mentioned to create a good soil and microclimate, to store humidity after rainfall and to provide shadow for grazing animals. Besides the advantages, participants however also stated that these natural barriers are impractical for the work with agricultural machinery. In addition, the hedges need to be maintained to not outgrow (e.g. in the past, branches of ash trees were cut and used as additional fodder for the cattle).

Such landscape elements also existed in Prägraten and Kals but were partly removed in the process of land consolidation, among others, to facilitate the work with machinery. Yet in both communities' interviewees stated that the awareness of the ecological and protective benefits of hedges and trees between agricultural land is again increasing. In Prägraten it was also reported that more people leave trees and hedges grow or even plant new ones. Yet, one interviewee doubted the effectiveness and utility of such natural barriers.

Mobility & Location

One participant stated that the **distribution of land for hay making across multiple sites with different local conditions** (e.g. dry/humid; nutrient-rich/nutrient-poor; higher/lower altitude) would be a favorable response to the increasing drought and the related hay yield losses. In this way the risk of yield losses might be diffused, as more divers land parcels can better cope with varying weather conditions (e.g. cultivating only land on the sunny side, might lead to higher yield losses than cultivating land that is allocated on the sunny and shady side

[6] „*Des send eigentlich, sen größteils Eigentumsgrenzen, und, des is entstanden eher mitn urbar machen und mitn Getreidebau. Donn hot am die Steine gemiaßt ausi tuan. Und wo hot ma sie hingebrocht? An die Grenze. Und do san nochand die Sträucher gewochsen drauf.*" (I6)

of the valley). It also allows for temporarily staggered grassland management/harvest as the speed of vegetational growth differs between the different locations (e.g. on alpine meadows the hay is later ready to be harvested than in the valley).

Table 13: List of local adaptation to climate change impacts (LACCI) in the crop and tree cultivation sector (incl. fodder cultivation).

Domain	Class	LACCI	Trend	Related LICCIs	Actor	Temporal scale	Degree of realization	Number of mentions
Livelihood organization	Livelihood (sub) system	Changes in (C.i.) agricultural diversification	More cereal and fruit tree cultivation	↑ mean temp.; Longer vegetation period	Individuals	Long-term	Partly implemented	8
	Size, structure & composition	C.i. crop and tree species composition	More legume and fruit tree species	↑ mean temp.; Longer vegetation period	Individuals	Long-term	Partly implemented	5
	Timing	C.i. timing and duration of seasonal activities (i.e. hay harvest)	Earlier hay harvest	Earlier vegetative growth of grassland species	Individuals	Long-term	implemented	4
	Infrastructure, construction & technology	Ci the construction of natural barriers to protect plantations	Revalorization of hedges, trees and dry-stone walls	↑ intensity of drought, mean temp. and wind strength/speed; ↑ frequency of dynamic flooding	Individuals and municipality	Long-term	Partly implemented	4
	Mobility & Location	C.i. long-term close-by horizontal relocation of cultivation fields (e.g. within the community/district):	Further spatial dispersion of fodder cultivation fields	↑ intensity of drought; ↓ pasture productivity	Unknown (u.)	Long-term	Idea	2
Livelihood related activities	Fertilizer demand	C.i. the use of natural fertilizer on plant cultivations	More (composted) manure	↑ intensity of drought; ↓ pasture productivity	Individuals	Long-term	Implemented	1
	Water demand	C.i. the quantity of applied freshwater irrigation with surface water (e.g. rivers and streams)/ Changes in the quantity of applied irrigation:	More irrigation of grassland, orchards and home gardens	↑ intensity of drought; ↓ amount of rainfall; ↓ pasture productivity	Individuals and municipality	Short to long-term	Implemented	8
		C.i. the quantity of rainwater for irrigation			Individuals	Long-term	Implemented	1

	Seeding/ Planting	C.i. re-sowing	More re-sowing as drought protection and pest prevention	↑ intensity of drought; ↓ amount of rainfall; ↓ pasture productivity; ↑ frequency of pests in pasture species (i.e. June beetle)	Individuals	Long-term	Implemented	6
	Weeding & Pesticide demand	C.i. the use of chemical pesticides on plant cultivations	Chemically treated barley	↑ frequency of pests in pasture species (i.e. June beetle)	Individuals	Short-term	Implemented	2
		Use of "beneficial organisms" for pest control	Chicken			Long-term	Implemented	2
			Beneficial organisms			Medium-term	Implemented	1
		C.i. weeding	Earlier fertilization with manure& less fertilization with slurry (*Anthriscus sylvestris & - Heracleum sphondylium*); Cutting in rosette stage (*Veratrum album*); Continuous cutting (*Heracleum mantegazzianum*)	↑ abundance of specific pasture species; ↑ distribution of wild plant species stated as invasive	Individuals and municipality	Short to long-term	Implemented	4

5.3.1.2. Livestock rearing and animal husbandry

Implemented

Livelihood (sub) system

In combination with other factors, the reducing fodder yields due to the increasing drought persuade some farmers to totally **stop livestock farming** in the long term. This was thought to concern mainly part-time farmers who then sell or lease their land or who focus on another agricultural production sector (e.g. only producing hay for sales; hold chickens instead of cattle). Participants emphasize that the mentioned developments are also strongly influenced by other than climate related factors: e.g. high work load through combination of part-time farming and farm external work; no farm successor; low profitability of small-scale farming.

Timing

Some farmers stated that during some extreme heat days which occurred in the last years, they started to keep the **farm animals in the stable during the day and to only release them on the pasture during the night**, to reduce the heat stress for the animals.

The earlier onset of spring and the related earlier start of vegetative growth have made it possible to let ruminants **start grazing earlier** in the year. Concerning the pasture availability, in some place the animals can also **go on the alpine pastures up to three weeks earlier** than 40-50 years ago. Many interviewees stated though, that the decision when to start grazing in the valley and on the alpine pastures strongly depended on the farmers individual ideology/philosophy of grassland management. On community managed alpine pastures this depends on the decision and philosophy of the respective agricultural community. One interviewee had the impression that many farmers are sceptical whether there will be enough fodder for the whole year, if the animals start to graze earlier.

Infrastructure, construction & technology

One participant stated that the **installation of hay drying plants** could be seen as one response to the harder predictability of rainfall. Yet the respondent clarifies that, a hay drying plants require a lot of power derived from renewable energy or not-renewable energy and is not the most sustainable adaptation measure.

Mobility & Location

For many participants, the **management of alpine pastures** was seen as an important element of the local adaptive capacity to climate change impacts. Letting farm animals graze on the alpine pastures was considered the best way to protect them from heat stress caused by the increasing temperatures and intense heat waves in summer. Furthermore, the grazing limits the progressing scrub encroachment and treeline rising, thus reducing the loss of biodiversity and the risk of erosion or avalanches. Yet most participants reported that the management of alpine pastures is progressively decreasing. Efficient alpine pastures would require a sufficiently high stocking density of grazing animals, manual cleaning (e.g. cutting and burning dwarf shrubs) of the land, maintenance of roads and paths etc. While the amount of work is increasing, also due to climate change impacts, the number of farmers/ people working per farm is decreasing. With them, also the stocking density of animals on alpine pastures is decreasing. This again encourages scrub encroachment which limits the available grazing area and results in a reduction of the number of animals farmers can put on alpine pasture. More frequent damages due to natural hazards are additionally increasing the work amount and costs required to maintain alpine pastures, thus limiting farmers motivation to continue alpine pasture management. Additionally, water shortage for livestock might become a problem on alpine pastures in the future. This has already occurred in different location in valleys surrounding the study site. Interviewees reported that in some of these cases, water has been transported from the valley up to the alpine pastures. Some interviewees stated that this might also be required in the study region at some point.

Feed demand

Figure 7 Steep mountain meadows where hay is being made, Virgen (Fuchs, 2020)

Another measure to contain scrub encroachment and to reduce avalanche and erosion risk, is **the mowing/haying of alpine meadows** (figure 7). This provides hay of high quality, supplementing the fodder resources in times of drought and decreasing hay yields in the valley. Furthermore, it increases the biodiversity. Yet, as for the alpine pasture maintenance, the lack of work force on farms and the lack of time are barriers to reinforce this practice. Also, participants stated that the accessibility of alpine meadows need to be adapted to modern circumstances. More roads or paths leading to the meadows are required, to descend the hay more easily. Former practices, like pulling down the hay with sleighs in winter, became too dangerous as well as too time and work intense for modern times: "*Where there is no way to get there, it [mountain haying] is no longer done. There were 10 people living in one house. Because I know when we were children, we were in the mountain meadows all summer. We mowed with the scythe, and in winter we pulled the hay down to the valley. That's no longer possible. One day of mowing, one day of haymaking and it has to be done. You don't have the time anymore. You're out of time. You are alone. It doesn't work anymore.*" [7] One participant thought that as long as it is affordable and easier to import fodder than to mow the mountain meadow, this adaptation will not be successful.

Related to the unpredictability of rainfall, the trend to do **more silage production** than hay making was mentioned as an adaptation measure. In contrast to hay, silo can also be made under more humid/rainy conditions, and thus decouples the fodder production more from the increasingly unsure local weather conditions. Yet, not all participants value this measures as sustainable in the long-term, among others due to the lower fodder quality of silage or the use of plastic foil.

To limit the higher activity of honeybees and the related fodder consumption during winter due to the increased temperatures, beekeepers **place beehives preferably on cool spots on the shady site of the valley**. To compensate the losses of honeybee's fodder resource due to their early activity in spring interrupted by cold periods in May/June, **beekeepers** provide them **supplementary feed** (e.g. sugar water).

7 *„Wo koa Weg zuacha geht, des..mocht ma nimmer. Zerscht wohnen in an Haus 10 Leit, nid, weil i woaß, wo ma Kinder woren, wor ma in gonzen Sommer in da Bergwiesen. Isch mit da Sensen gemaht worden, im Winter is es owi gezogen worden. Des geht heit ois nimmer. An Tog mahen, an Tog Heurechen und es muaß fertig sein. Hosch jo die Zeit nimmer. Bisch a aloan. Geht nimmer.“* (I2)

Partly implemented & ideas

Size, structure & composition

While not total stopping cattle farming, some farmers are thinking about reducing **their number of animals** in the long-term (e.g. reduce rearing) to be able to provide them with their farm grown fodder, despite the increasing drought. However, in the short-time interviewees have not sold animals to cope with fodder shortages. This would not make sense, as the price for livestock is especially low in the moments of fodder shortage. Also, interviewees had the impression that **more farmers are again keeping rare/locally adapted cattle breeds** (i.e. Tiroler Grauvieh and Original Pinzgauer Rind), which might increase the adaptive capacity regarding the decreasing hay yields due to increasing drought. This is in stark contrast to habit of some local farmer to keep highly productive cattle breeds like Holstein Friesians. Such breeds have a very high fodder demand, which requires the additional purchase of concentration fodder and is even less compatible with the decreasing pasture productivity.

Several participants explained that in the past the husbandry of different farm animal species, which are grazing and browsing helped to clear the alpine pastures and keep them open. One participant stated that it would be favourable to **re-increase the farm animal diversity**, in order to stop scrub encroachment and to use the fodder resources on the mountains more efficiently – also in regard to the decreasing hay yields in the valley. For example, more horses grazing after the cattle, sheeps and goats for higher and more difficult to access areas, or maybe even seasonal herding of goats.

Table 14: List of local adaptations to climate change impacts (LACCI) in the livestock rearing/animal husbandry sector.

Domain	Class	LACCI	Trend	Related LICCIs	Actor	Temporal scale	Degree of realization	Number of mentions
Livelihood organization	Livelihood (sub) system	C.i. livestock activity: livestock keeping	Less livestock farmers	↑ intensity of drought; ↓ pasture productivity	Individual	Long-term	Implemented	4
	Size, structure & composition	C.i. quantity of livestock	Less livestock	↑ intensity of drought; ↓ pasture productivity	Individuals	Long-term	Idea	3
		C.i. the composition of livestock species	More divers composition of livestock species	↑ intensity of drought; ↓ pasture productivity; ↑ scrub encroachment of alpine pastures/ meadows	Individuals, agricultural communities	Long-term	Idea	1
		C.i. the composition of livestock land-races/breeds	More locally adapted livestock land-races/breeds	↓ pasture productivity; ↑ intensity of drought	Individuals	Long-term	Implemented	2
	Timing	C.i. the timing and duration of daily pastoralist activities	Grazing during night	↑ intensity of heat waves/ frequency of days with extreme temp.	Individuals	Short-term	Implemented	3
		C.i. timing and duration of seasonal pastoralist activities	Earlier grazing;	Earlier onset of spring; Longer vegetation period	Individuals and agricultural communities	Long-term	Implemented	6
			Earlier drive up to alpine pastures					4
	Infrastructure, construction & technology	C.i. the construction and quality of storage facilities for products related to livestock rearing, excluding water storage (e.g. fodder storage)	Increasing installation of hay drying plants	↓ predictability of rainfall	Individuals	Long-term	Implemented	2

	Mobility & Location	C.i. the practice of transhumance or other seasonal (circular) movement activity (e.g. following food/water availability) / Changes in temporal/seasonal close-by vertical relocation of livestock (changes in elevation)	Management of alpine pastures	↑ mean temp; ↑ intensity of heat waves/ frequency of days with extreme temp.; ↑ scrub encroachment of alpine pastures/ meadows; Tree line rising; ↑ climate-induces hazards	Individuals; agricultural communities	Long-term	Implemented	7
Livelihood related activities	Feed demand	C.i. the composition of feed for livestock/Ci the collecting fodder	More mowing/haying of alpine meadows	↑ intensity of drought, ↓ pasture productivity; ↑ scrub encroachment of alpine pastures/ meadows; tree line rising	Individuals	Long-term	Implemented	3
		C.i. the compositon of feed for livestock/ changes in cultivation/growing fodder or using by-products as fodder/changes in collecting fodder	More silage production	↓ predictability of rainfall	Individuals	Unknown (u.)	Implemented	2
		C.i. quantity of extra feed	Supplementary feeding of honeybees	↑ mean temp in winter; Earlier onset of spring; ↑ mean temp in spring ; ↓ decreasing livestock productivity (i.e. honey yields)	Individuals	Short-term	Implemented	3

5.3.1.3. Household capacities

Implemented

Financial capital & mobility and location

As mentioned earlier in relation to livestock farming, interviewees emphasized that more and **more farmers are stopping to farm**, due to different developments: farms are lacking successors, agriculture does no longer seem profitable for the new generation and young people prefer **working in less nature dependent sectors**, with fixed working hours, holidays, and secure income. Most farmers are already part-time farmers, who have a second off-farm job. For some this double burden becomes too big and the following generation is discouraged by the workload, which eventually leads to the abandonment of farming and the orientation towards other income sources. This trend is not driven by climatic change, yet climate change impacts may intensify the situation. Increasingly experienced problems with naturals hazards, drought, yield losses, pest infestations or scrub encroachment, which are projected to amplify in the future, are an additional motivator to become financially independent from natural dependent sectors like farming. Some participants noted, though that the implementation of home office due to the Covid pandemic enhanced the compatibility of on- an off-farm work. Trying to reduce the need to commute in future was mentioned as opportunity for the continued existence of part-time farms.

Yet, well-working combinations of non-nature related and nature related livelihood combinations exist. This is especially true for the combination of agriculture and tourism. Many part-time farmers rent rooms and apartments or work in the alpine sport sectors. The local tourism was perceived to strengthening the adaptive capacity of the communities, as it is still rather small-scale and nature related. Most of the additional income from tourism reaches the local small-scale tourism businesses and does not flow off with external investors.

Natural capital

In an attempt to conserve biodiversity, **the plantation of "Blühstreifen"** was reported to have increased in the last years. Yet, one participant claims that this measure is not achieving a lot given the scope of local biodiversity loss.

Safety behaviour & Physical capital (incl. infrastructure, construction & technology) & Human capital

In Kals it was reported that the **"danger zones", which indicate the threat from dynamic flooding and avalanches, had to be expanded** over the last year, as big floods are projected to occur more frequently than before (e.g. centenarian floods have been upgraded to 50-year floods). Consequently the settlement area is more and more limited and the buildings/object whose construction were authorized some years ago, are now situated in zones of high risk. Those affected (i.e. residents and people interested in buying and constructing) do not always want to acknowledge that.

Besides preventing the construction of vulnerable infrastructure in dangerous areas, also **more natural and technical barriers** are being constructed to protect the already endangerd buildings/objects against natural hazards. It was reported that in Kals the water volume of the big floods in 1965/1966 has been exceeded several time, but thanks to the constructed protections along the river/stream course no damage has occurred. Also, in areas where the protection forest has been eradicated by extreme events/natural hazards, barriers must be and are being constructed. Modern technique and machinery were mentioned to facilitate the construction of barriers but the constructions were accompanied by high costs. Interviewees stated that in the long-term some areas are likely to be abanodned, as the protection through technical barriers is limited. A common concern was the open question of who will pay the increasing expenses for barrier constructions in the future.

Additionally, more and **more measuring points are being installed in rivers and streams**, serving as early warning systems for floods, dynamic flooding and mudflows. Additionally, regular control tours in the mountains are done by the commission for avalanche rescue to detect potentially dangerous irregularities (e.g. avalanche blocking and damming up a stream).

Human health

All participants who shared the impression that the sun intensity has increased stated that they had **to protect themselves better from the sun than in former times**: wearing shirts, preferably long-sleeved shirts, when working in the summer sun, use more sun cream, trying to avoid the sun and preferring the shade, especially on the mountains.

External resource dependency

A common adaptation measures to the drought related hay yield losses in the last 3-4 years, was **the additional purchase of hay from outside the community.** For many interviewees this was mentioned as exceptional, something they never needed to do before. Most of the interviewed farmers stated to purchase only as much fodder as they really needed to get through the winter. Yet it was reported that other farmers import bigger amounts of hay, partly also, because they have more grazing livestock units than their land can feed, or just to ease the work process (e.g. silage is locally produced, hay imported).

Interviewees mentioned several barriers/disadvantages of this coping measure. It is difficult to plan whether or how much additional hay needs to be bought: buying early would be cheaper, but it is more difficult to estimate how much hay you will actually need in winter because you do not yet know how many calves you have, how many you are going to rear and what the cattle price will be. Also, organic hay was stated to be scarcer and the purchase especially complicated (e.g. demanding permission to buy additional fodder) and expensive. Some interviewees also reported that it was difficult to get hay produced nearby and that the quality of imported hay is often lower than of the one growing and harvested on-farm/on the mountain meadows.

Partly implemented & ideas

Financial capital

Participants mentioned the local processing of agricultural products as a behavior which enhances the adaptive capacity of local nature related livelihoods. Processing raises the value of the raw products and local marketing could strengthen the local economy. Several farmers and wild plant gatherers are still processing and selling their own products (e.g. cheese, bread, jams, liquor, herb salt). Yet, many stopped doing so, out of convenience or lack of workforce. Yet another reason mentioned was the decline of local processing facilities (e.g. butcher, bakeries, mills).

Besides processing facilities, local marketing facilities are needed to enhance adaptive capacity. In this regard interviewees believe that the regional management is going in the right direction: regionality becomes more important, more farm shops and local suppliers opened in the last years (e.g. “Bauenlader” in Virgen; “Handwerksladen” in Kals).

Beside such changes on the local and regional level, interviewees also expressed the need to change the agricultural subsidy system. In general subsidies should be distributed in a way that small-scale agriculture can be maintained, and that the sustainable work done instead of the area one possessed is subsidised. This would counteract the development of more and more local processors closing down (e.g. slaughterhouse) and more and more farms ceasing to exist.

Social capital

As mentioned earlier, alpine pasture management enhances the adaptive capacity of the local communities, but is nonetheless declining due to, among other reasons, the lack of work force. However, an interviewee described the **community management of alpine pastures** as a form of management which is (potentially) more capable to cope with recent and future climate change impacts (e.g. more damage through more frequent dynamic floods, mudflows, more intense storms). **Community owned and/or managed alpine pastures** (e.g. agricultural communities, cooperative or association as holder of rights of use) are thought to be more effective because the work (e.g. cleaning pastures; construction; herding) and costs (e.g. construction of stables) can be shared among several people. It would also be reasonable that as many animals would graze on the alpine pastures as are needed to keep them open, independent from the livestock rights of each farmer. Also, alpine pastures could be divided according to their utilization (e.g. separate part for suckler cows, milking cows, young cattle). The local prevailing usage rights of pastures and forest is, however, hampering some of these attempts. Each farmer only has the right to put a certain predefined number of animals on the alpine pastures. To change this base right an unanimous decision would be needed, which was stated to be hard to get. Some interviewees thus see the need to effect certain ownership changes in the alpine pasture regulations to enable a better adaption to future climate change impacts. One interviewee said, however, that it cannot be denied that community-based management can also implicate dealing with interpersonal conflicts.

Another interviewee also emphasized that it was needed to **share the responsibility and costs of alpine pasture maintenance not only within the agrarian, but within all of society**. Especially because the existence alpine pastures are of interest for the society at large (e.g. biodiversity, cultural aspects, tourism, natural hazard protection etc.).

Community-based/intercorporate sharing of machinery and tools, as well as sharing workforce and helping each other out as neighbours was also considered as a chance to continue or reinforce land management practices which strengthen the adaptive capacity of the local communities, but are hampered by the lack of workforce and time (e.g. mountain haying, diversification of agricultural production, processing of local timber). Sharing tools, machinery and workface can not only save time and money, but also keeps emissions lower (mitigation). With ten exceptions many interviewees had, however, the impression that the practice of collective action and sharing is declining since the 70ties. Most people either have their own machinery or the work is done by agricultural contractors from outside the communities. Another problem with community-based sharing of machinery and tools is that they are needed at more or less the same time in the year. Especially because part-time farmers are temporally even more limited. Good organisation and agreement is required, but not always easily implemented and achieved.

In Prägraten one interviewee highlighted the **voluntary help of different local clubs for civil protection before and cleaning up after extreme or hazardous events**. It was stated that the number of people who are employed for this task are far too little to cope with extreme situations. This applies especially to the restauration of the hiking path network, which is too extensive to be maintained by only 2-3 employees per community. The interviewee sees the cooperation between the municipality and local clubs as a fruitful future adaptation measure to the impacts of climate extremes and natural hazards, which could compensate the shortage in staff.

In Kals the help of farm external people was also seen as a chance to cope with the increasing damage on alpine pastures through extreme events and natural hazards, as well as with scrub encroachment. Sometimes volutneers connected to the Nationalpark Hohe Tauern or ecologically and agriculturally interested students come to help out on alpine pastures. It is deemed possible that this could be expanded.

Natural capital

Most interviewees shared the opinion that **mixed forests are more resilient** to extreme events, natural hazard, drought, pest infestations and better for the soil than monocultures of p*icea abies*. Many participants had the impression that in forestry the plantation of deep rooting *larix decidua* and deciduous tree species has increased and been promoted over the last years. Also, the practice of natural regeneration was thought to be more common.

Furthermore, the interviewees suggested that forest owners need to **better maintain** their **forest parcels, to prevent the overaging of the tree stand** and with-it, forest damages like the recent windsnap, windthrow and snowbreak.

An **immediate clearing and removal of damaged/fallen/torn timber after extreme climate or hazardous events** was also considered as an adaptation to climate change impacts, as it can prevent cascading effects like, for example, an extensive bark-beetle infestation. Yet this was considered difficult, as forest owners do not have the workforce and time to cope with such high amounts of damaged forest and timber. Also, many forest parcels are difficult to access and hardly extrapolable. Specialized tools and machinery are required for these tasks; thus, professionals have to be hired to do the work. This is expensive, while the timber price is low, thus the effort is financially unappealing to forest owners. Some interviewees thought that the public sector (e.g. the state of Tyrol) should provide better financial support.

External resource dependencies

Some participants also stressed that the **local processing (e.g. sawing or chaffing) and use (e.g. for construction or heating) of locally grown timber** would increase its value and moderate the financial losses in the case of forest damages due to increasing climate-induces hazards or extreme events.

Table 15: List of local adaptations to climate change impacts (LACCI) regarding household capacities.

Domain	Class	LACCI	Trend	Related LICCIs	Actor	Temporal scale	Degree of realization	Number of mentions
Household organization	Financial capital	C.i. income from other work (in a non/low natural dependent sector/buisness)	More income from non/low natural dependent sectors – less farming	↑ climate-induces hazards, ↑ intensity of drought, ↓ pasture productivity, ↑ occurrence of pests in forest and grassland; ↑ scrub encroachment of alpine pastures/ meadows	Individuals	Long-term	Implemented	7
		C.i. income through market interactions/selling livelihood-related products	More facilities to sell locally produced and processed livelihood-related products	-	Individuals, municipality, region	Long-term	Partly implemented	2
		C.i. income from selling prepared food, hand(i)craft etc.	More selling of locally produced and processed agricultural products	-	Individuals	Long-term	Partly implemented	3
		C.i. receiving remittance or other financial support	Subsidies according to work and not to area	-	State	Long-term	Idea	2
	Physical capital (incl. infrastructure, construction & technology)	C.i. the construction of natural/technical barrier constructions against hazards/riks for housings	More natural and technical barriers	↑ climate-induces hazards; ↑ mortality of wild plants (i.e. more storm-damaged timber); ↑ frequency and intensity of wind and storms	Municipality, state	Long-term	Implemented	3

	Natural capital	C.i. active renaturalization /regeneration through afforestation or plantings (e.g. of native species)	Fostering mixed forest planation and natural regeneration	↑extreme climate events, ↑ climate-induces hazards, ↑ intensity of drought; ↑ occurrence of pests in forest	Individuals, agricultural communities, municipality/state	Long-term	Partly implemented	5
			Clearing and removal of storm-damaged timber					4
		C.i. other means to increase or protect natural capital (e.g. biodiversity)	Plantation of "Blühstreifen"	↓ biodiversity	Individuals and municipality	Short-term	Implemented	2
	Human capital	C.i. the use of institutional/technical/external information and warning systems	More water level measuring points in rivers and streams	↑ frequency of dynamic flooding&mudflows	Municipality, state	Long-term	Implemented	1
	Social capital	C.i. participation in community-based/common/collective actions/support	Collective management of alpine pastures	↑ climate-induces hazards; ↑ scrub encroachment of alpine pastures/ meadows; heavy rainfall	Individuals and agricultural communities	Long-term	Partly implemented	3
		C.i. collective /community-based sharing	Sharing costs and responsibility of alpine pasture maintenance		Unknown (u.)	Long-term	Idea	1
			Sharing machinery, tools, workforce, time	-	Individuals and agricultural communities	Long-term	Partly implemented	5
		C.i. requesting/receiving external help/assistance/support in times of emergency	Local clubs and external volunteers helping with civil protection and restauration	↑ climate-induces hazards; ↑ scrub encroachment of alpine pastures/ meadows	Individuals, agricultural communities, municipality	Long-term	Partly implemented	2

	Mobility & Location	C.i. permanent faraway relocation of other livelihood/work activties (e.g. outside the community/district; to urban area) without moving residence	More commuting to off-farm jobs	See “financial capital”	Individuals	Long-term	Implemented	5
Household related activities	Human health	Other health protections, including well-being (e.g. sun protection)	More sun protection	↑ sun intensity	Individuals	Short-term	Implemented	3
	External resource dependencies	C.i. buying other products and recources related to livlihood (e.g. feed)	Increased hay purchase	↑ intensity of drought; ↓ amount of rainfall; ↓ pasture productivity	Individuals	Medium-term	Implemented	7
			Local processing and use locally grown timber	↑ climate-induces hazards	u.	Long-term	Idea	2
	Safety behavior	C.i. other behavior with (pre-) caution related to living	Expanding “danger zones”	↑ climate-induces hazards	Municipality, state	Long-term	Implemented	1

6. Discussion

6.1. Methodological limitations and potential biases

Some methodological limitations arose in the context of the study's sampling and data collection, partly due to unanticipated obstacles. To acknowledge potentially resulting biases on the results, the main limitations are discussed below.

The first two parts of data collection were planned for early spring 2020, as study participants following natural resource-based livelihoods were thought to be the most available at this time of the year. Because of a nationwide lockdown due to the SARS Covid-19 pandemic, the data collection was postponed to summer 2020. During the summer months participants following natural resource-based livelihoods are very busy. This made it more difficult to find willing interview participants which impacted however the sample design.

The quota sampling was less balanced than planned and not all quota sufficiently represented (young women and men; old women; forestry). Male, 40-65 years old interviewees following an agriculture related livelihood were most strongly represented and thus biased the results in this direction. This had several reasons: (1) Livelihood categories: Most local people follow several natural related livelihoods, of which farming is the most time-intensive one. Thus, most interviewees were either full- or part-time farmers who followed a second not-nature related profession (category "agriculture"). Many of those interviewees also owned and managed forest parcels (category "forestry"). Additionally, several hunt in their free-time (category "hunting") or carry out other secondary professions, as e.g., bee-keepers or mountaineering guides (category "others"). (2) Gender: It was more difficult to convince women to participate in interviews. The Men appeared more comfortable to talk, often women suggested their male partners as study participants. Key-informants mainly suggested male contact persons, partly also because many of the local nature related livelihood activities (e.g. hunting, forestry, beekeeping, mountain guiding) are men dominated. (3) Age: Only few people older than 65 years, willing and capable of giving an interview have been suggest by key-informants or other interviewees. People younger than 40 years were less available during the time of field research, as it was the main haying season.

During data collection it became apparent that asking for observations of climate change impacts, corresponding adaptations and barriers (as originally anticipated) within one semi-structured interview was too much. The interviews became too long and the thematic frame too broad. This provided a broad overview, but little detail. To address this, I excluded all questions about barriers to adaptation. Questions about adaptation, were sometimes difficult for participants to answer, as they did not necessarily identify general/common land management practices as climate change adaptation. Often, participants also equated adaptation with mitigation.

The third part of data collection, the focus group discussions, coincided with another nationwide lockdown and thus could not take place in person as planned. Instead, they were conducted online which had impacts on the sampling and the nature of the FGD.

Due to the online modus of the FGD, the motivation to participate was lower (e.g. technical aversion; personal connection missing). This resulted in a lower number of participants and a less divers sample composition. Not all livelihood categories could be represented, and in some cases only one person per livelihood was present in the FGD, which hampered the exchange of views and opinions between local experts. Also, there was a strong gender bias. Only one woman participated in the focus groups, as no other woman wanted to participate in the online format of the discussions. This has potentially resulted in an incomplete representation of the local collective perception of climate change.

Due to the online modus, time was more restricted and the session more structured. Thus, it was more difficult for participants to enter into a real discussion with each other. At some times, participants who were accustomed to online communication interacted more. The FGD rather resembled a group interview. Therefore, it was often difficult to detect the level of agreement between participants on certain climate change impacts. This too might have biased the represented local collective perception of climate change.

6.2. Observations of change

The results showed that in all three Eastern Tyrolean communities people observed a variety of changes in the climate, as well as resulting climate change impacts in the physical, the biological and the human system. Additionally, some changes which were only partly attributed to climate change and a few changes which were ascribed to other drivers, have been observed in the biological and the human system.

Climate and environmental change in the Austrian Alps

A comparison with scientific climate change documentations shows that many of the collected local observations correspond with past records and future projections of anthropogenic climate change impacts documented by the Austrian Panel on Climate Change (APCC 2014) in the Austrian Alps.

The increase in mean temperature (APCC 2014, p. 353) and the more frequent occurrence of temperature extremes (i.e. more heat days and warmer nights) (APCC 2014, p. 85), the intensification of global radiation (APCC 2014, pp. 355–356), as well as the prolongation of the vegetation period (APCC 2014, 491ff) were among the most often observed changes in the **climate system** and they correspond with climate changes documented by the APCC. Yet, some other frequently mentioned local observations, like the increase in frequency and intensity of heavy rainfalls and storm events, could not be confirmed by the APCC. To predict a significant trend of such small-scale extreme events the spatial and temporal resolution of available climate data or climate models is considered to not be sufficient (APCC, 2014, pp. 86–87). Also, the local observation that precipitation is decreasing in summer deviates from past climate records, which show an increase in mean precipitation in the West of Austria (APCC 2014, p. 84). However climate models imply that in the southern and western parts of the Alps precipitation might decrease during spring, summer and autumn, while it might increase in winter towards the end of the 21th century (APCC 2014, pp. 93–94). The local observations potentially offer more detailed information about the quality of precipitation and drought events (timing, duration, distribution, intensity). Farmers described for example, that rainfall is often too intense to infiltrate and sufficiently moisturize the soil, whichwould stimulate vegetation growth. Depending on the soil type and exposition this can lead to local drought damages.

Regarding the **physical systems,** most local observations match the findings of climate change impacts in other parts of the Austrian Alps. This mainly concerns changes in snow and ice: the retreating glaciers, the significant shift from snow to rainfall and the resulting decrease in snow amount and snow cover duration, as well as the increasingly higher snowline in summer. Aditionally, the observed increase in soil temperature and the associated consequences, like the degradation of permafrost (APCC 2014, p. 431), and the increased occurrence of pests in grassland (APCC 2014, p. 530) have also been documented in the APCC. The validation of the reported increase of local natural hazardous events is associated with more unpredictability. In accordance with local observations, an increase in wet snow avalanches in lower altitudes due to higher temperatures has been documented (APCC 2014, p. 559) and rockfall is predicted to increase with the increasing regression of permafrost (APCC 2014, p. 569) in the Alps.

All locally observed climate change impacts on the **biological system** match general patterns of changes in the alpine biosphere attributed to climate change. Shifts in the phenology of wild and cultivated plants (APCC 2014, 335; 497) correspond to the earlier flowering and budding of fruit trees and specific wild plant species (e.g. *Vaccinium myrtillus*) observed by several participants. The findings that migratory birds tend to arrive earlier in the year and that they shift their areal to the North due to climatic changes (APCC 2014, p. 506) fits study participants' (?) explanation that magpies have increased in the study area because they are stopping to migrate to the South during winter. Ticks were also reported to have increased and will further expand their spatial and temporal activity with increasingly favourable temperatures (APCC 2014, p. 644)., This matches locals' observation that ticks occur in higher altitudes. Their spread is considered a potential risk for the transmission of infectious diseases to livestock and humans (APCC 2014, p. 519).

The fact that almost a third (28%) of all observations of environmental changes were only partly or not at all related to climate change, proofs the presence and significance of other factors driving local change. Most of these observations and their attributed drivers – in the biological systems as well as the human system – are mirrored in literature. In regard to the frequently mentioned decrease in forest health, other studies provide, for example, evidence that climate change is a significant driver for forest damages. Two causes among others are the increasing bark beetle populations and the weakened defence mechanisms of trees suffering from drought stress (APCC 2014, p. 526). Just as local observants, these studies also emphasize, that forest damages are strongly influenced by forest management, and that the increasing forest cover together with past silvicultural mistakes (e.g. cultivation of spruce outside its natural range) might have a stronger impact on Austria's forest damages than climate change (APCC 2014, p. 526). Similarly, observed environmental changes such as bush encroachment/land abandonment and rising timberline, are also attributed to an interplay of non-climatic (e.g. land use change/ land abandonment) and climatic factors by other studies (APCC 2014, p. 524).

Most of the observed climate change impacts and partial or non-climate change related changes in the **human system** are also consistent with the results of other studies in the Austrian Alps. Examples are the favouring of grassland pest (e.g. *Melolontha melolontha* and *Amphimallon solstitale*) due to the warmer climate (APCC 2014, p. 530), and the increased danger for hikers and mountaineers and the closing of mountain paths due to rockfall and other changes in the relief system, especially in the Tyrolian Alps (APCC 2014, p. 569). The frequently mentioned earlier start of vegetative growth and the decreased productivity of grassland are, however, more difficult to validate, as they are influenced by many factors (e.g. seasonal precipitation, expositon, soil properties, management techniques) (APCC 2014, p. 528). The duration of the snow cover in spring is, for example,considered to be especially decisive for the duration of the vegetative period and the productivity of grassland in alpine and subalpine locations (APCC 2014, p. 528). The observed increase in root spreading weeds may, however, be a long-term consequence of drought damage in grassland (APCC 2014, p. 529).

Interstingly, several environmental changes that observers did not associate with climate change are, according to the literature, partly related to climate change. For example, plant and animal species are displaced or disappearing because their optimal habitat is shifting with the higher temperature, and they cannot adapt fast enough (APCC 2014, p. 56). This explains the local reduction in river trout, which has also been reported in other places in the Austrians Alps (APCC 2014, p. 516). Range shifts due to temperature changes also affect all other animal groups and have a positive or negative impact depending on the species and situation. For several species endemic to the Austrian Alps, range losses are expected with advancing climate change (APCC 2014, p. 506). Climate change increases the pressure on ecosystems and biodiversity, which are already strained by various factors. Vice versa, measures to promote biodiversity can also enhance climate change mitigation (APCC 2014, p. 110).

The high degree of agreement between local knowledge-based observations of climate change impacts and scientific knowledge can be interpreted as evidence that local knowledge, based on a long-term interaction of people with their local environment, is also empirical and thus similar to scientific knowledge (Klein et al. 2014). In addition, the overlap may also be due to the fact that the local population is already highly sensitised to the topic of climate change, as it is very present in public discourse and people are well informed through educational institutions and various media. Thus, personal observations and externally acquired climate change knowledge complement each other and/or converge. The local observations offer a high-resolution examination of environmental change (e.g. changes in plants and animals on the species level) and provided place-specific information on the local environment (e.g. soil characteristics, expositions, local weather phenomena) which are valuable for the interpretation of environmental changes. Furthermore, they enable the consideration of the local socio-economic context (e.g. past and present land management practices), which enables an estimation of the impact of not-climatic factors on environmental change as well as their influence on the implementation of climate change adaptation. To profit from both types of knowledge and to increase the probability of climate change statements, I would suggest a more profound comparison between the local observations with climate data of a similar spatial and temporal scale (Reyes-García et al. 2016).

Local indicators of climate change impacts

Similar Most of the observations (21) obtained in Eastern Tyrol were made in the **climate system**. This corresponds to to local observations of climate change impacts by communities across the globe (Reyes-García et al. 2016). The high number might be due to the fact that changes in the climate are most direct and thus easier to identify by most people in comparison to climate change impacts on biophysical or socio-economic systems. Based on these climatic changes, many cascading impacts spanning different systems, have been described by the local population. For example, the higher soil temperatures (physical system) due to milder winters (climate system) were held responsible for the easier overwintering and increased reproduction of certain insects (biological system). This in turn caused damage as pests (e.g. cockchafer) in agricultural meadows and pastures (human system) in combination with the increasing drought (climate system) were observed to reduce growth in meadows and pastures, making them more even more susceptible to pest infestation. Thus, in many cases, an interaction of several changes in the same or in different systems is considered as responsible for further change impacts. These findings underline how local observations can help to understand the impacts of climate change on complex and interrelated ecological and socioeconomic processes (Savo et al. 2016). The mutual interactions of climate change impacts within and between the different systems makes it difficult to depict them in a linear way. To get a comprehensive picture I suggest presenting all climate change impacts and their corresponding drivers (climate and not climate related) in a network (Reyes-García et al. 2019).

As in many other local communities across the globe (Reyes-García et al. 2016), the second biggest group of climate change impacts observed (11 observations) were located in the **physical system**. All changes in the physical system were either directly related to climatic changes or indirectly through cascading effects incited by climate change (e.g. the rising snowline leads to more glacial retreat which again causes an increase in dynamic flooding). The increasing temperatures in summer and winter were, for example, seen as main drivers for the ongoing changes in the cryosphere, i.e. the reduced average snow amount during winter, the reduction of the glaciers, the melting of permafrost and the warming of the soil. This is a trend commonly observed in alpine ecosystems across the globe (Savo et al. 2016). In case studies all across the globe, changes in hydrology and cryosphere were the most frequently observed (Reyes-García et al. 2016). In contrast, only few changes in hydrology have been observed in the study area. This is also contrary to other case studies which report that the reduction of fresh water was one of the most commonly observed changes in the physical system, involving numerous impacts in biological and socio-economic systems (Savo et al. 2016). In regard to the study area, it is important to note that several participants mentioned a concern that, water shortage will become a future challenge, if glacial melting and drought accelerate. Participants also linked changing snow and ice conditions (part of hydrology) to the increasing occurrence of natural hazards. Natural hazards seem to be particularly relevant for the local population, as they pose an existential threat to residential areas and infrastructure, and inflict damage on agricultural and forestry land. The increased frequency and unpredictability of landslides have been observed in other mountain regions too (Savo et al. 2016)

The number of climate change impacts (11 observations) concerning the **biological systems** is equal to those concerning the physical system. These predominantly include climate change impacts on the terrestrial wild flora and fauna. In contrast to the climate and physical system, system many different climate change impacts were mentioned in the biological that were only observed by a small number of people. For comparison, in global studies local observations were also found to be the most diverse and highly specific in the biological system (Savo et al. 2016; Reyes-García et al. 2016). This reflects the complexity and diversity of biological systems, which demand long-term and close observation to detect clear trends. Numerous participants stated that they are not spending enough time in nature to be able to observe changes in the wild terrestrial or aquatic fauna and flora. It is noteworthy that descriptions of the observed changes in the biological systems were more detailed and complex than in the other three systems.

Despite the great number of climate change impacts on the local biophysical systems only few changes (8 observations) in the **human system** were observed. This is in line with findings from communities across the globe (Reyes-García et al. 2016). One reason for this could be that climate unrelated drivers, including the decreasing number of farms, abandonment or intensification of land management, are held responsible for local socioeconomic changes and have greater relevance for the local population than climate change. Reyes-García et al. (2019) assumed that the low number of observations in socioeconomic systems is due to the higher visibility of not climate change related drivers, like integration in market economies, specialization, diversification or migration impacting local livelihoods.

The climate change impacts on the human system observed by multiple participants reflect the main livelihood activities practised by the study participants. Thus, most changes concerned the agricultural and forestry sectors, which again is in line with observed climate change impacts around the globe (Reyes-García et al. 2016). Nonetheless, physical (e.g. public and private property; infrastructure) and natural (e.g. protection forest) capital relevant for human safety and the tourism sector and thus an important financial resource were also mentioned to be impacted by hazardous or extreme weather events resulting from climate change. This is characteristic of mountain areas, where the populated area is limited and highly exposed to natural hazards.

Impacts of climate and environmental changes for management and livelihoods

The local observations of the participants can help to get a clearer picture of how and in which sectors the local population feels affected by climate and environmental changes (Green and Raygorodetsky 2010). Agriculture and forestry as well as the tourism sector and the general safety of the local inhabitants were identified as especially impacted by the interplay of climate change and not climate change related drivers.

In particular, the increasing crop losses (e.g. hay harvest; honey harvest) due to drought and increasing temperatures play an crucial role in local agriculture. Also relevant are the increased reproduction of pests and their spread into higher altitudes (e.g. cockchafer; ticks). Another rather negatively perceived development is the advancing scrub encroachment in alpine pasture areas, as well as the rise of the timberline, which have both ecological (i.e. loss of biodiversity) and protection-related (i.e. erosion risk) consequences and lead to a loss of forage area and cultural landscape. The more frequent occurrences of climate-induced hazards (e.g. landslides) and intensification of extreme heat and precipitation events (flucutations between drought and heavy rainfall events) also harm farmers. They can damage agricultural land and forest areas, roads and buildings. However, some climate change impacts are also perceived as positive, such as the lengthening of the vegetation period and the growth-promoting milder temperatures - provided that there is sufficient precipitation to use the extended periodical productivity.

Forests and forestry are affected by similar impacts as agriculture. Participants mentioned the increase and spread of pests (e.g. bark beetle), as well as the increase in forest damages due to extreme climate events (e.g. windthrow) and climate-induced natural hazards (e.g. landslides). Theses developments were associated to both financial loss and the loss of the protective function of forests.

The loss of protective forest, the increasing bush encroachment of alpine pastures and the accumulation of extreme climate events and natural hazards are particularly relevant in the mountain region, as some of the municipalities are highly exposed to related hazards may be at risk (residential areas, infrastructure, tourist facilities). The expansion of potential danger zones, the decreasing amount of snow in winter and the loss of cultural landscape can also have a negative impact on tourism, on which the local population is heavily dependent.

The observed climate-related impacts on land management practices are strongly influenced by the local socio-economic context and historical background. In regard to this context and background, the decline in agricultural and forestry management (e.g. lack of labour power; low profitability; lack of farm successors) and the increased exercise of unsustainable management practices (e.g. overuse of natural resources) are of particular relevance. Participants related both decline and unsustainability to a lack of support for small-scale and sustainable management on the one side and a favouring of agricultural intensification and industrialization on the other side. The mountain region of Tyrol has been cited as one of several examples for progressive land abandonment in Europe in a study requested by the European Parliament's Committee on AGRI. Especially "hard to access" terrain, like steep slopes and high mountainous areas, is increasingly abandoned (Schuh B et al. 2020, p. 51). This is due to the topographical constraints as well as populations declines in remote places (e.g. less accessible side-valleys) which are related to the hampered integration of young women into the labour market and higher level of unemployment (Schuh B et al. 2020, pp. 53–54). There is increasing recognition that "*natural stresses are always interrelated with other system stress (including economic globalization) – climate change can only be fully understood in relation to other non-climate drivers that either mitigate or aggravate the climate change impacts." (Nelson et al. 2009, p. 272)*

6.3. Drivers of change

From all collected observations of change, most (72%) were directly attributed to climate change and 11% were rated as not climate change driven. The remaining 17% of all observations were stated to be driven by a combination of climate change and other non-climate stressors. They are all located in the biological and in the human system. This might be because the region is characterised by cultural landscape, thus there is an overlap of biological and human systems where anthropogenic intervention is diverse and very common. As a result, it can be difficult to clearly distinguish whether a change is driven by climate change or other human interventions, mainly changes in land management. As summarized by Nelson et al. (2009), "*natural stresses are always interrelated with other system stress (including economic globalization) – climate change can only be fully understood in relation to other non-climate drivers that either mitigate or aggravate the climate change impacts" (Nelson et al. 2009, p. 272).* This mirrors how complex and interrelated ecological and socio-economic systems are. Also other studies reported of the difficulty to distinguish between social impacts that are caused by climate change versus other non-climate related factors (Barnes et al. 2013; Rosenzweig and Neofotis 2013).

Within the local context these not climate change related driving factors are mostly overlapping with the significant changes in local livelihoods and the related land management practices (e.g. intensification of grassland management; abandonment of alpine pastures) which shaped the study area during the last decades. An example that was frequently mentioned was the general decline of labour power leading to a decrease in the sustainable management of alpine pastures and mountain meadows which fostered scrub encroachment. This subsequently resulted in a loss of biodiversity, increased erosion and the reduction of grazing area for livestock. In many of the examples described by the local population, climate change additionally amplified the ongoing livelihood changes. Scrub encroachment due to land management abandonment, for example, was thought to be accelerated by climate warming.

Another reason why so many observed changes in the biological and human system were attributed to not climate change related drivers may be that impacts of climate change in these systems are less visible to the naked eye than not climate change related drivers, like land use changes or migration. The fact that LEK based observations gain little recognition was also considered as one possible reason for the low density of data on local observations in the European context (Savo et al. 2016). Several study participants also argued that climate change is not yet severe enough to feel impacts on their own livelihoods, but that this will change in future if climate change continues to develop.

6.4. Local adaptation and barriers

Nature of adaptation

The local population practices some adaptation and coping methods, at least partially, and cultivates behaviours/habits/management practices that increase their adaptive capacity or reduce their vulnerability to climate change impacts. Several ideas for future adaptation measures or for increasing adaptive capacity were mentioned.

Some of the applied adaptation measures target specific climate change impacts and are oriented towards combating the symptoms of these impacts (e.g. irrigation a response to drought). Other adaptation approaches mentioned are more holistic and target several climate change impacts at once. For example, by promoting livestock grazing on alpine pastures during summer, heat stress for livestock can be decreased, scrub encroachment and subsequently erosion and biodiversity loss inhibited.

As stated in other literature, also not climate related external forces and conditions can impact the sensitivity of systems towards change and influence the nature of adaptation (Smit et al. 2000). This was the case for several local responses to change. For example, farmers do not only stop livestock farming in order to adapt to the decreasing availability of hay/fodder, but also because, among other factors, small-scale farming became less profitable, off-farm work provides more convenient working conditions or farm successors are lacking. Adaption processes are also recognised to potentially modify climate change impacted systems in a way that their sensitivity to climate stimuli is reduced (Smit et al. 2000). This fits the third type of identified adaptions, which comprise behavioural patterns or adaptation ideas that did not directly target specific climate change impacts, but were described to increase the adaptive capacity or reduce the vulnerability of communities to current and future climate change (e.g. community farming, neighbourhood support, local processing and marketing, diversification of agricultural production.)

Regarding the temporal scale, mainly medium to long-term adaptations were suggested, they included for example comprehensive changes in community interaction (e.g. shared use and management of alpine pastures) or the allocation of natural resources (e.g. water for irrigation). Only few short-term coping measures were identified. One example is that local farmers purchased external livestock fodder to compensate their hay yield losses caused by drought events. This approach would not be sustainable in the long-term. Similar to other studies around the world (Schlingmann et al. 2021), adaptations that are purely science-based or proposed by external institutions following a top-down approach (e.g. chamber of agriculture) were mentioned but cannot be identified as "local". This mainly concerned single-target adaptations (e.g. recommendation/promotion for pest control).

However, many of the more holistic oriented adaptation measures, behavioural patterns and ideas for adaption seem to stem from or be informed by LEK, as they represent practical knowledge and experience of managing dynamically changing socio-ecological systems in ways that enforce their adaptive capacity (Pearce et al. 2015; Berkes et al. 2000). These LEK intrinsic measures are for the most part perceived as useful by the local population. Yet, in many cases they have been adjusted to present-days demands. This means, for example, that mowing mountain meadows is still considered a sustainable land management practice, but its continuing implementation requires the use of motorized tools and easy accessibility via roads. This does not signify the end of placed-based knowledge and practice but rather demonstrates its survival through hybridization with other knowledge forms which are better suited for present conditions (Aswani et al. 2018; Gómez-Baggethun and Reyes-García 2013).

Many of the mentioned local adaptation measures correspond to typical examples of LEK intrinsic practices: the maintenance of biodiversity, ecosystem services and biocultural diversity (Gómez-Baggethun et al. 2013) are, for example, being addressed by the sustainable use and management of alpine pastures and mountain meadows, the maintenance of hedges and stonewalls as cultural landscape elements, the diversification of agricultural practices (e.g. more cereal, fruit and vegetable cultivation). The suggestion to manage agricultural area collectively, to engage in neighbourly help or to share the use of agricultural inputs/machinery are further local examples for social and institutional organisation based on LEK, which influence the communities ability to act collectively (Nakashima et al. 2012)

Despite the existence of these adaptation approaches, many barriers to adaptation have been identified. Although the local communities are obviously capable to generate local knowledge based adaptations and to transform them according to their needs, the transfer and application of LEK (Gómez-Baggethun and Reyes-García 2013) seem to be hindered in various ways. Some participants thought for example that a great part of the local population does neither feel concerned nor responsible enough for climate change, as to actively engage in adaptation. This might partly depend on local actors' worldviews and value systems which influence their personal motivation to adapt or to implement pre-set adaptation measures (Adger et al. 2009). But also, exogenous factors were mentioned to hamper the transfer and application of local adaptation. For example, the interest of the younger generation to carry on LEK based management is reduced by the increasing unprofitability and the high work demand of nature-related livelihoods in comparison to employment in better-paid and more secure not natural resource related sector. This is consistent with the identified impoverishment of LEK worldwide due to globalization, modernization and market integration (Aswani et al. 2018). In order to efficiently reduce the vulnerability of the study area and enhance adaptive capacity through LEK these not climate related factors need to be targeted.

Local adaptation in management and livelihoods

Overall, numerous different adaptation measures or behaviours and management practices that could increase adaptive capacity were mentioned by different individuals. Although many climate change impacts are being perceived and the local population is strongly affected by these impacts in different spheres of life, comparatively few of these adaptive measures were implemented. This may partly be a methodological bias, as many adaptation measures were often not perceived or labelled as such by the participants. To address this, interviews could for example be complemented with participant observation in further research. Another reason could be various factors and developments which, in the opinion of the local population, prevent or make adaptation more difficult (see subchapter “barriers”).

The adaptation measures that were frequently mentioned and also implemented or at least partially implemented are changes in grassland management and in animal husbandry. These include the increasing use of irrigation systems as a reaction to the increasing drought and the associated fodder harvest losses. Apart from this, many farmers are compensating for climate-related crop losses by buying in external feed. A remarkable trend is that in recent years many small part-time farms have stopped keeping livestock or, in some cases, have stopped farming all together. This reaction is due to a variety of factors, the increasing difficulties caused by climate change impacts being one of them. The decline in farming also means that more and more inhabitants are deriving their income from non to low natural dependant sectors. In many cases, these sectors/employers are located outside the local communities, which explains, among other things, an increase in people commuting to work.

Not all climatic changes were rated as risk, some were seen as opportunities. Moving mowing and haying times to earlier start dates, an earlier start of livestock grazing, as well as the earlier start of the use of alpine pasture were repeatedly mentioned as an adaptation to the earlier start of the growing season. Many participants also mentioned that due to the higher temperatures and the longer growing season, more and different types of fruits and vegetables can be grown. It was also speculated by many that the change in climate could be beneficial for cereal cultivation.

The preservation of alpine farming and related land management practices was highlighted by many participants as a response to many climate change impacts. This is not only about adapting agriculture, but also about preserving biocultural diversity, the protective function and the tourism function of this ecosystem.

In the context of forestry, increasing afforestation with mixed forest and natural regeneration were frequently mentioned as long-term adaptation to the diverse climate change impacts affecting the forest. In addition, the removal of damaged wood as soon as possible was mentioned as an adaptation to the increasing extreme climate events and natural hazards.

The changes in the use of social capital as an adaptation to multiple climate change impacts or to increase adaptive capacity were also particularly noticeable. These include, for example, the joint management of alpine pastures to better cope with difficult conditions (e.g. scrub encroachment; natural hazards), the shared ownership or use of machines and tools among farmers, neighbourly help, especially for activities that require a high level of labour input (e.g. mowing mountain meadows) or the cooperation with local associations or external volunteers for protection against and clean-up after extreme weather events or natural hazards.

Barriers

Although not explicitly asked in the interviews, the study participants referred to many barriers which they judge *“as having a negative influence on the process and reduce the chances of successful outputs*” of local climate change adaptations as Biesbroek et al. (2013, p. 1127) define barriers to climate change adaptation. Furthermore, they also suggested several ways in which these barriers could be overcome.

Some of these barriers relate to particular adaptation measures (e.g. barriers to the application of irrigation systems). This reflects the fact that barriers to adaptation are highly context dependent (Biesbroek et al. 2013). Therefore, a categorisation as for example proposed by the IPCC (2014) is often difficult. For this reason and because unplanned results are concerned this study does not suggest a categorisation of these barriers. Nevertheless, recurring patterns/groups of barriers which influence many of the mentioned adaptations directly and indirectly are evident and can be assigned to overarching trends.

One of these trends is the lack of labour power in agriculture and forestry. Young people migrate or work in not nature related sectors, thus a lack in farm succession emerges. Additionally, small-scale agricultural and forestry undertakings become unprofitable as the need for costly investments cannot be paid for due to the low prices of agricultural products. Also, in all three mountain communities the tendency to either "grow or give way" arrived: few big and intensively managed farms are replacing many small part-time farms. This hampers the implementation or revitalization of sustainable land management which could increase the adaptive capacity of the local communities (e.g. maintenance of alpine pastures and meadows; diversification of agriculture; local processing and marketing of agricultural and forestry products).

Furthermore, some adaptation measures are barriers for other adaptations, e.g. the abandonment of farming as a profession and a shift to not-nature related income sources and migration are hampering the implementation of adaptations which are work intensive and would require an increase of labour force (e.g. management of alpine pastures and meadows or diversification of agriculture). This confirms the hypothesis that adaption (e.g. abandonment of farms), is not per se good, as trade-offs, feedbacks and negative consequences can arise from adaptation (Eriksen et al. 2011).

As mentioned earlier in relation to LEK transmission and application, also system internal factors like personal attitudes and values might limit the societal adaptation (Grothmann and Patt 2005; Adger et al. 2009). Besides a lack of concernment and self-responsibility towards climate change impacts, participants also thought that people were too comfortable to implement certain work intense adaptation measures, that they were clinging to old, no longer appropriate management habits and are sceptical about external "scientific" advice served top down.

In many cases it can be argued that not climate related factors or processes are driving environmental change which simultaneously are hampering a successful and sustainable adaption to these changes. For example, the decrease in work force was among many other factors responsible for profound changes in the local land use practices (e.g. abandonment of alpine pastures; loss of agricultural diversity). These changes are directly or indirectly enforced by climate change (e.g. more extreme climate events increase the risk for natural hazards and erosion) but at the same time they lower the adaptive capacity of theses socio-ecological systems towards climate change. To really achieve a successful implementation of sustainable adaptation it is thus indispensable to recognise and understand the relation between and the impacts of all of these climate and not climate related endogenous and exogenous factors on local livelihoods and human behaviour.

7. Conclusion and Outlook

The aim of this case study was to gain a better understanding of people's perception of climate and environmental changes on the local scale in the European Alps, under consideration of the place specific historical background and socio-economic context. Following a social sciences approach, local indicators of climatic and environmental change impacts and their respective drivers, as well as corresponding local adaptions were identified in three rural communities in the Eastern Tyrolian Alps.

The findings of the study show that the local population of Prägraten, Virgen and Kals observed a variety of climatic and environmental changes in their communities. The majority of these changes were attributed to climate change, revealing that the local population perceives climate change and its related impacts on climatic, physical, biological as well as human systems. Identifying such local indicators of climate change impacts can help to break down the global phenomena climate change on a local and more personal level, thereby bringing it closer to local people's reality of life (Reyes-García et al. 2016). A comprehensive comparison of the observed climate change impacts with local climate data could additionally provide the local population with proof that what they are observing are actual consequences of anthropogenic climate change.

Furthermore, applying a uniformed methodology for data collecting allows for a comparison of the identified local indicators of climate change impacts to local climate change impacts of other regions or climate zones (Reyes-García et al. 2019). By enriching the data base of local climate change observation in the European Alps, this study contributes to guiding science and policy towards a more local and social-science informed perspective on climate change. Moreover, the results help to explain correlations between different climate change impacts and drivers within and between biophysical and socio-economic systems. The findings also highlight those impacts which are particularly strongly felt by the local populations (Barnes et al. 2013), thus revealing their most pressing concerns and needs (Savo et al. 2016). In addition to comparing observations to climate data, they constitute a significant contribution to scientific data on climate change (Mistry et al. 2016).

Although climate change was the most often mentioned driver of local environmental change, almost a third of all observed changes were considered to be partly and fully driven by other factors. The local population thus perceives to be strongly impacted not only by climate change, but by a combination of climate change and not climate change related stressors, like land abandonment or migration. As meaningful adaptation and mitigation should be directed towards the actual drivers of change, it is thus essential to better understand which are the main drivers and how they interact, especially because climate change is either enforcing other ongoing changes or conversely these changes hamper the adaption and/or mitigation to climate change. Hence, both must be considered in the development and implementation of adaptation and mitigation measures, otherwise they will not be sustainable in the long-term (Eriksen et al. 2011).

Agriculture and forestry were found to be the sectors mainly affected by both climate change impacts and other global changes. At the same time, the implementation of sustainable management practices in both sectors can potentially increase the adaptive capacity in regard to global change. In other case studies around the world, LEK was found to strengthen communities' resilience and help to respond to diverse agents of global environmental change (Gómez-Baggethun et al. 2013) and was recognized as a valuable experiential knowledge source to inform adaptation and mitigation strategies (Eriksen et al. 2011). In Eastern Tyrol, this applies for example to land management practices, developed over generations which create a living environment in the alpine high mountains and its nature (Bätzing 2015, p. 17).

Since such knowledge and practices are still known by part of the local population, these could be used as internal resource for place-based adaption.

LEK based management practices are still being applied, often in hybridised forms, combined with modern techniques and further inspired by external scientific or popular knowledge. Through the promotion of biocultural diversity, LEK can be a key contribution to successful climate change adaption (Gómez-Baggethun et al. 2013). A loss of this place-specific knowledge would threaten the conservation of cultural and biological diversity (Aswani et al. 2018). Thus, it is important to further explore LEK based practices and think of ways to integrate them in local contexts, to adapt them to ongoing global changes and to promote their transmission. It will be important to do this in a bottom-up way, in cooperation with the local population – that is: to learn from them, to take their problems seriously, to target their needs and to develop locally based adaptation measures everyone accepts.

However, the findings of the study also revealed that these local adaptations are hindered by a variety of barriers. Both, barriers resulting from local people's worldview and belief system (e.g. subjective perception of risk and adaptability) and from overarching socio-economic-politic developments (e.g. industrialization of agriculture vs. land abandonment) need closer investigation as they play a key role in whether adaptation takes place and is successful (Eriksen et al. 2011). A better understanding of the origin and functioning of these barriers could help to find suitable ways to overcome them (Adger et al. 2009). To achieve successful and sustainable adaption Nelson et al. (2009) summarizes that an "*effective inclusion and participation of local communities*" is needed, which leads "*to a focus on institutional adjustments and community reorganizations*" (Nelson et al. 2009, p. 272).

This case study was an explorative study. In order to be able to deepen the insights gained and to make generalisations about how the socio-economic circumstances influence the perception of climate change, the associated adaptive responses and related barriers, we suggested to conduct surveys in a follow-up study.

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11.1. Information sheet and consent form

11.1.1. Information sheet

Lokale Indikatoren für die Auswirkungen des Klimawandels

Die Universität BOKU in Wien ist die österreichische Partnerin des LICCI-Projektes an der Autonomen Universität Barcelona, Spanien. Im Rahmen dieses Projektes würden wir gerne mehr über die Veränderungen erfahren, die Sie in Ihrer lokalen Umgebung beobachtet haben und wie sich diese Veränderungen auf Ihr tägliches Leben auswirken. Dazu möchten wir mit den Einwohnerinnen und Einwohnern der Gemeinden Prägraten am Großvenediger, Virgen und Kals am Großglockner ein paar Interviews führen und sie zu ein bis zwei Diskussionsrunden einladen. Wir werden die in dieser Studie gesammelten Daten ausschließlich zu Forschungszwecken verwenden und nicht für kommerzielle Zwecke nutzen. Diese Studie wird mit vielen Haushalten in verschiedenen Ländern weltweit durchgeführt. Das Forschungsprojekt wird vom Europäischen Forschungsrat finanziert, und die Mittel werden von der Autonomen Universität in Barcelona verwaltet.

Verfahren und Dauer: Unsere Projekt-Partnerin Anna Fuchs wird für 6 bis 8 Wochen bei Ihnen in der Region wohnen. Sie wird Sie und andere EinwohnerInnen der drei Gemeinden mehrmals besuchen, um Fragen über die Veränderungen in der Umwelt, deren Zeuge sie geworden sind, zu stellen (z.B. Veränderungen des Pflanzenbestandes; im Verhalten oder der Anzahl von Tieren; Veränderungen im Boden, im Wasser oder im Eis) und wie diese Veränderungen ihr Leben beeinflussen. Jedes Gespräch kann etwa ein bis zwei Stunden dauern. Wenn Sie und Ihre Gemeindemitglieder*innen sich entscheiden, an der Studie teilzunehmen, werden wir Sie (a) um ein paar persönlichen Informationen (Alter, Ausbildung, Beruf) bitten, sowie Ihnen Fragen zu den Veränderungen in der Umwelt, die Sie beobachtet haben, stellen. Außerdem würden wir Sie bitten (b) an 1 bis 2 Kleingruppentreffen teilzunehmen, bei denen wir gemeinsam über Veränderungen in der Umwelt diskutieren werden. Beide Methoden (Interview und Gruppendiskussion) werden in der Forschung häufig genutzt.

Der Datenschutz: Ihre persönlichen Daten sind nur dem Kernteam des Projekts zugänglich und werden absolut vertraulich behandelt (d.h. niemand kann Sie identifizieren). In Veröffentlichungen oder Berichten werden die Befragten nicht namentlich genannt. Die Daten werden für keinen anderen Zweck als für wissenschaftliche Veröffentlichungen und Konferenzpräsentationen verwendet. Die Daten dürfen nicht für kommerzielle Zwecke verwendet werden. Wir werden immer sicherstellen, dass Dritte die Person, die die Daten zur Verfügung gestellt hat, nicht identifizieren können. Die gesammelten Informationen über lokale Veränderungen in der Umwelt werden in einer webbasierten Plattform hochgeladen, so dass jede/r Interessierte diese einsehen kann.

Die Teilnahme: Die Teilnahme an der Forschung ist absolut freiwillig, und alle TeilnehmerInnen werden gebeten, vor Beginn der Forschung ihre freie und informierte Zustimmung zu geben. Sie haben auch das Recht, jederzeit und ohne Konsequenzen von der Forschung zurückzutreten. Es gibt keine individuellen Zahlungen für die Teilnahme an der Studie. Jedoch glauben wir, dass das Forschungsprojekt dazu beitragen könnte, Einzelpersonen und Dörfer zu stärken, da diese Forschung mithilft, ihr lokales Wissen wertzuschätzen und die Aufmerksamkeit darauf zu lenken, wie die lokale Bevölkerung von den Auswirkungen des Klimawandels betroffen ist.

Vorteilsausgleich: Die gesammelten Informationen werden genutzt, um die Öffentlichkeit und die Wissenschaft auf die lokale Landbevölkerung aufmerksam zu machen und sie darüber zu informieren, wie deren Wissen zu einem besseren Verständnis der Auswirkungen des Klimawandels und der Anpassung an den Klimawandel beitragen kann. Wir werden diese Informationen auch innerhalb und zwischen den verschiedenen an der Forschung beteiligten Gruppen austauschen. Das Projekt wird Außenstehenden helfen, ein besseres Verständnis für das Wissen und die Beobachtungen der lokalen Landbevölkerung zu erlangen. Am Ende der Feldarbeit werden wir die vorläufigen Ergebnisse allen Teilnehmern und Teilnehmerinnen präsentieren, sowie das, durch diese Forschung gewonnene Wissen im Rahmen eines Workshops teilen.

11.1.2. Free prior informed consent form

Einverständniserklärung zur Erhebung und Verarbeitung personenbezogener Interviewdaten

Betrifft: Diplomarbeit zu „Wahrnehmung lokaler Umweltveränderungen“ an der Universität für Bodenkultur (Wien) von Anna Fuchs im Rahmen des Projektes „Local indicators of climate change impacts (LICCI)” der Universitat Autònoma (Barcelona)

Teilnahme: Ich bitten Sie um Ihre Teilnahme, da wir an Ihren Erfahrungen interessiert sind und Sie in einem der für unsere Studie ausgewählten Dörfer leben. Ihre Teilnahme an dieser Studie ist absolut freiwillig und Sie können jederzeit ablehnen, weiterzumachen. Die einzige Alternative zur Teilnahme ist die Nichtteilnahme. Es gibt keine negativen Konsequenzen für Personen, die sich gegen die Teilnahme entscheiden oder die sich zu Beginn der Teilnahme und später für den Rücktritt entschieden haben.

Datenschutz: Die persönlichen Daten, die wir im Rahmen dieses Projekts sammeln, stehen nur dem Kernteam des Projekts zur Verfügung und sind absolut vertraulich. In Veröffentlichungen oder Berichten werden Sie nicht namentlich genannt. Die Daten werden für keinen anderen Zweck als für wissenschaftliche Veröffentlichungen verwendet. Persönliche Daten werden nicht verkauft, weitergegeben oder auf andere Weise an Dritte weitergegeben, die sie für andere Zwecke als die Forschung verwenden könnten. Auch in diesem Fall stellen wir sicher, dass Dritte die Person, die die Daten zur Verfügung gestellt hat, nicht identifizieren können. Die allgemeinen Informationen über lokale Veränderungen in der Umgebung werden auf eine Internetplattform hochgeladen, so dass jede/r Interessierte sie einsehen kann.

Nutzung: Die gesammelten Informationen werden verwendet, um WissenschaftlerInnen und die Öffentlichkeit im Allgemeinen darüber zu informieren, welche Veränderungen Sie in der lokalen Umwelt sehen und wie sie sich auf Sie auswirken. Am Ende der Erhebung werden wir alle TeilnehmerInnen, sowie die restliche Gemeinde (VertreterInnen des Gemeinderats und der Verwaltung, Mitglieder lokaler Institutionen), in einem von Ihnen gewünschten Format (z.B. einer Broschüre, einem Workshop), über die Forschungsergebnisse informieren. Wir werden unsere vorläufigen Ergebnisse vorstellen und Sie fragen, ob Sie der Meinung sind, dass unsere Ergebnisse zutreffend sind.

Kontakt: Victoria Reyes-Garcia ist die Gesamtverantwortliche für das Projekt und Anna Fuchs ist die örtliche Verantwortliche. Sie können beiden Fragen zum Projekt oder zur Datenerhebung stellen. Victoria Reyes-Garcia können Sie schriftlich am Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spanien kontaktiere oder per E-Mail an Victoria.reyes@uab.cat, sowie telefonisch unter 00 34 93 581 8976 erreichen. Anna Fuchs können sie entweder direkt vor Ort antreffen, telefonisch unter 0043 680 3343150 erreichen oder ihr ein E-Mail an anna.fuchs@students.boku.ac.at senden. Wenn Sie Fragen zu Ihren Rechten als ProjektteilnehmerIn haben, können Sie sich an proteccio.dades@uab.cat wenden. Um sich mit der zuständigen Person in Verbindung zu setzen, können Sie sich an Anna Fuchs wenden, da sie über die vollständigen Anweisungen verfügt und den Kontakt in Ihrem Namen ohne Kosten herstellen kann.

Mit Ihrer Zustimmung zur Teilnahme und Ihrem Einverständnis verzichten Sie auf keine Ihrer gesetzlichen Rechte, Ansprüche oder Rechtsmittel. Sie können das Formular selbst unterschreiben oder eine andere Person bitten, in Ihrem Namen zu unterschreiben.

Ich habe die Informationen in der Einwilligungserklärung gelesen (oder jemand hat sie mir vorgelesen). Ich hatte die Gelegenheit, Fragen zu stellen, und alle meine Fragen wurden zu meiner Zufriedenheit beantwortet. Mit der Unterzeichnung dieser Einverständniserklärung erkläre ich mich bereit, an dieser Studie teilzunehmen.

Name des Teilnehmers/der Teilnehmerin:

Unterschrift Datum, Ort

Ich habe die Forschung zum Thema erklärt und alle seine/ihre Fragen beantwortet. Ich bestätige, dass er/sie die in dieser Einverständniserklärung beschriebenen Informationen gelesen hat und freiwillig der Teilnahme zustimmt.

Name der LICCI-Partnerin: Anna Fuchs

Unterschrift Datum, Ort

11.2. Interview guides

11.2.1. SSI: Local context

Local livelihoods and seasonal calendar

Begrüßung; Vorstellen; Einverständniserklärung für Erhebung persönlicher Daten; Einverständnis für Audioaufzeichnung einholen; kurz das Ziel des Interviews/des Projektes erklären.

1. **Sind Sie hier in der Gemeinde geboren/ Seit wann leben Sie hier in …?**
2. **Wollen Sie mir ein wenig über ihren Lebensweg hier in … erzählen?**
   - Ausbildung (Schule, Beruf)
   - (Erwerbs-)tätigkeiten
   - Rolle in der Gemeinde
3. **Können Sie mir schildern welchen beruflichen Hauptaktivitäten zur heutigen Zeit in der Gemeinde nachgegangen wird?**
   - Naturbezogen (z.B. Landwirtschaft, Forstwirtschaft) und nicht naturbezogen (z.B. Tourismus, Bau, Handwerk, Handel, Bildung, Gesundheits- und Sozialwesen)
   - ganzjährige oder saisonale Tätigkeiten (welche und wie ist die Verteilung)
   - haupt- oder nebenberufliche Bereiche
4. **Sie haben jetzt … (z.B. Landwirtschaft, Forstwirtschaft) genannt, fallen Ihnen sonst noch Bereiche ein, in denen die Leute hier in der Gemeinde in und mit der Natur arbeiten?**
   - Andere Bereiche z.B. Jägerei, Fischerei, Imkerei, Wildsammeln…
   - Werden Aktivitäten in diesen Bereichen beruflich oder hobbymäßig ausgeübt?

   … in der Landwirtschaft:

   - Welche Arten der landwirtschaftlichen Bewirtschaftung werden in der Gemeinde betrieben? (Viehwirtschaft, Obstanbau, …, „Mischbetriebe“)

- Grünland-/Viehwirtschaft: welche Tiere, welche Produkte (Eier, Milch, Fleisch…) , ob/wie verarbeitet und vermarktet
- Almwirtschaft: welche Tiere; Milch (Abgabe/Veredelung) oder. Fleisch;
- Obstanbau: welche Sorten, ob/wie verarbeitet und vermarktet
- Ackerbau/Gemüseanbau/Erwerbsgarten: welche Kulturen/Gemüsesorten, ob/wie verarbeitet und vermarktet
- Hausgärten: was wird angebaut, Nutzen: Selbstversorgung?

… in der Forstwirtschaft:

- Wem gehören die Wälder/ wer ist für die Bewirtschaftung verantwortlich? (privat, bundesforste;)
- Wie wird bewirtschaftet? (lassen od. aufforsten; besondere Bestimmungen wegen des Nationalparks; welche Baumarten…)
- Wie wird das Holz genutzt?
- (Hat sich die Bewirtschaftung im Vergleich zu früher verändert?)
- Wer hat viel Erfahrung/ kenn sich gut damit? Wie zeigt sich das?

… in der Jagd:

- Wer jagt und in welchen Gebieten? (Vereine/ Einzelpersonen; privat/öffentlich/Nationalpark)
- Was wird v.a. gejagt und wie wird gejagt?
- Was für Wildtiere gibt es heutzutage (und im Vergleich zu früher)?
- Was wird mit dem erlegten Wild gemacht?
- Wer hat viel Erfahrung/ kenn sich gut aus damit? Wie zeigt sich das?

…Wildsammlung:

- Wer geht Wildsammeln?
- In welchen Gebieten (privat, öffentlich, Nationalpark)?
- Was wird v.a. gesammelt?
- Wie wird es genutzt (Verarbeitung; Verkauf; Eigengebrauch)?
- Wer hat viel Erfahrung/ kenn sich gut aus damit? Wie zeigt sich das?

…selbes Schema mit allen genannten naturbezogenen Aktivitäten

Start mit „Saison Kalender“: um eine bessere Vorstellung davon zu bekommen, wann welche Hauptaktivitäten in den verschiedenen genannten Bereichen hier in der Gemeinde stattfinden, würde ich gerne mit Ihnen gemeinsam einen sogenannten ‚Saisons-Kalender‘ aufzeichnen. [*Kurz die Vorgehensweise am schon vorbereiteten Kalender beschreiben*]

5. Ich würde jetzt die einzelnen Aktivitäten hier in der Gemeinde, von denen Sie vorher erzählt haben einzeln im Kalender eintragen und durchbesprechen. **Zu Beginn: in welche Saisonen würden sie den Jahresverlauf hier einteilen?**
6. *Falls die interviewte Person selbst einer „naturbezogenen Tätigkeit“ nachgeht, mit dieser starten.*
   Wollen Sie mir genauer die verschiedenen Aktivitäten/Phasen in [der Viehhaltung/ Ackerbau/ Obstbau/ Forst/ Jägerei/ Imkerei/ Wildsammeln…] **am Beispiel des letzten Jahres schildern?** (z.B. Abkalben, Heuernte, Baumschnitt…) **Was haben sie gemacht und wann, über den Verlauf des Jahres?** Sie können

gerne mit jenem Zeitpunkt des Jahres starten, der für sie den Beginn einer Saison/Tätigkeit bedeutet.
Fragen zu den einzelnen Tätigkeiten:

- **Wo** werden die einzelnen Aktivitäten ausgeführt
- **Wer** führt die Aktivitäten aus (Familienmitglieder, Angestellte) – **Alter, Geschlecht,**
- **Mit Hilfe welcher Geräte/Maschinen etc.** werden die Aktivitäten ausgeführt?
- **Sind diese Aktivitäten auch mit bestimmten (traditionellen) Festlichkeiten o.ä.** verknüpft?
- Welche Personen/Personengruppen bei Ihnen in der Gemeinde haben **viel Erfahrung mit und viel Wissen über** diese Tätigkeit/Aktivität? (Unterschiede zwischen Frauen/Männer?)
- **Entspricht der geschilderte Verlauf des letzten Jahres auch den anderen vergangenen Jahren?** Oder gibt es Abweichungen, Veränderungen, …?

Local timeline

Begrüßung; Vorstellen; Einverständniserklärung für Erhebung persönlicher Daten; Einverständnis für Audioaufzeichnung einholen; kurz das Ziel des Interviews/des Projektes erklären.

1. **Sind Sie hier in der Gemeinde geboren/ Seit wann leben Sie hier in …?**

Start mit „Zeitleiste“: Damit ich auch noch eine Vorstellung von der Geschichte der Gemeinde bekomme würde ich gerne mit Ihnen diese Zeitleiste ergänzen. [*Kurz die Vorgehensweise an der schon vorbereiteten Zeitleiste beschreiben*]

2. **Können Sie mir erzählen was Sie über die Geschichte der Gemeinde wissen und wir versuchen die genannten Ereignisse zeitlich auf der Zeitleiste einzuordnen?**
   Vorher: Recherche was wir schon über die Gemeinde wissen;
   Falls es den Personen schwer fällt sich an die zeitlichen Daten zu erinnern, den Bezug zu persönlichen Ereignissen suchen (z.B. War das vor/nach der Geburt ihrer Kinder/Enkelkindern; Was/Wo haben sie zu der Zeit gearbeitet etc.)
   Gespräch an den folgenden Themen entlang leiten:
   - **Seit wann gibt** es die Gemeinde schon?
   - Sind Menschen **zu-, weggezogen** (woher, wohin), gibt es **mehr/weniger alte/junge** Menschen als früher (Demographischer Wandel über die Jahre, Migration, Besiedlungsmuster...)?
   - **Wem gehören die Flächen** in der Gemeinde/wie und auf wen ist das Land hier in der Gemeinde aufgeteilt? War das früher anders? Warum und ab wann hat sich das verändert?
     Haben sich (auch) die **Tätigkeiten der EinwohnerInnen** verändert? Wie, warum und ab wann?
     Und sonst **im Leben der Menschen/ der Gemeinde**? Was ist heute anders als früher? (Landbesitz, Landbesitzentwicklung, Trends in der Interaktion mit Märkten oder Veränderungen in den Aktivitäten zum Lebensunterhalt → mit Angabe wann diese Trends etc. ca. angefangen haben)

   Bei den folgenden Ereignissen soll so genau wie möglich herausgefunden werden, wann sie stattgefunden haben. Es geht um Ereignisse, die für die gesamte Gemeinde relevant waren/sind:

- Können Sie sich an **besonders extreme Wettereignisse** erinnern (z.B. Starkregen, Hitzewelle, Stürme…) (Extreme Wetterereignisse)
- Gibt es andere **extreme Naturereignisse/Naturgefahren,** die den Leuten in der Gemeinde in Erinnerung geblieben sind? (z.B. Überschwemmungen, Muren, Lawinen, Steinschlag…)
- Prägende/Besondere **Ereignisse im Dorfalltag** (z.B. Sterbefälle/Geburten, Feierlichkeiten, Bauten…)
- **Andere wichtige Ereignisse** (z.B. Elektrizität, Straßenbau, Konstruktion von Skilift…)

11.2.2. SSI: Local observations and climate change adaptation

Perceived environmental changes and drivers

1. **Wenn Sie an die vergangenen Jahre/früher zurückdenken, habe Sie bei ihrer Arbeit oder in ihrem Alltag Veränderungen im [*] wahrgenommen/gefühlt/beobachtet? Wenn ja, können Sie mir diese schildern?**

   → [*] Interview entlang der verschiedenen Ebenen des LICCI-Trees führen

2. **Wissen Sie seit wann Ihnen [**hier die beobachtet Veränderung nennen**] aufgefallen ist?**
3. **Welche Ursachen/Auslöser für diese Veränderung nehmen Sie wahr/beobachten Sie?**
4. **Haben Sie den Eindruck, dass diese [**beobachtete Veränderung, die mit dem Klima in Verbindung gebracht wird**] sich direkt oder indirekt auf ihr alltägliches Leben oder ihre Arbeit auswirken?**
   a. Wenn ja, können Sie mir schildern, wie sie sich auswirken?

Adaptation/coping measures

Immer direkt im Anschluss an die Schilderung jeder beobachtete Veränderung nach Anpassungsmaßnahmen fragen

5. **Haben Sie ihre Arbeitsweise/Lebensweise/Alltag aufgrund [beobachtete, Klimawandel bedingte Veränderung] verändert – wenn ja, wie?**

   → [**] Interview entlang der verschiedenen Ebenen des LACCI-Trees führen

6. **Von wem geht diese Veränderung aus? Wer hatte die Idee dazu?**

[*] LICCI-Tree

(a) Witterung (Klima): Wetter/Jahreszeiten; Temperatur; Regen; Wind; Stürme…

(b) physikalische Umwelt (Hydro-, Relief-, Pedosphäre): Boden, Flüsse/Bäche/Seen, Berge, Schnee, Gletscher

(c) biologische Umwelt (Biosphäre und Ökosystemleistungen): Wildtiere, Pflanzen, Fische

(d) Leben/Arbeit der EinwohnerInnen: Nutzpflanzen und -tiere, Weiden/Wiesen, Krankheiten

[**] LACCI-Tree

(a) Haupterwerb (z.B. Landwirtschaft): (1) Organisation und (2) spezifische Tätigkeiten

(b) Haushalt: (1) Organisation und (2) spezifische Tätigkeiten

Question guide 2: During the interview one driver of change + the corresponding adaptation/coping strategy will be talked through one after the other (→ at least that's the theory) – e.g. mention/describe change and its effects on people → ask right after this whether they do something about it or not

11.2.3. Online FGD

1. Willkommen:

Ich will euch nochmal herzlich Begrüßen und mich bedanken, dass ihr heute dabei seid.

Zu Beginn, ich bin Anna – ihr kennt schon meine Stimme vom Telefon, ich hoff jetzt könnt ihr auch alle das Gesicht dazu sehen. Ich hab mir, dass ja ausgemalt wie wir dann alle entspannt in x zusammensitzen, Tee trinken und über das Wetter reden. Aber es freut mich, dass wir jetzt zumindest so zusammenkommen und ich hoff ihr habt es alle gemütlich vor eurem Computer.

Ich bin übrigens nicht alleine hier – sondern meine Studienkollegin x ist auch hier – sie unterstützt mich heute indem, sich um technische Dinge/Probleme kümmert, die Uhr im Blick hat, damit wir nicht überziehen.

2. Überblick

Ich will euch noch mal kurz erklären warum wir heute hier sind.

Ich studiere in Wien an der BOKU ökolog. Landwirtschaft und für meine Abschlussarbeit mache ich bei einem größeren von der EU geförderten Projekt mit (LICCI), dass von der Uni in Barcelona ausgeht.

Dabei geht es darum zu erfahren welche Veränderungen im Klima und der Umwelt Menschen die viel in der Natur sind bzw. stark von ihr abhängig sind im Vergleich zu ihrer Kindheit/zu früher/ in den letzten Jahren in ihrer lokalen Umgeben beobachten.

Das Ziel ist es herauszufinden was die direkt betroffenen Menschen beobachten, wie sich diese Veränderungen auf ihr Leben auswirken und wie sie darauf reagieren. Dafür werden Daten von verschiedenen Forscherinnen überall auf der Welt erhoben und miteinander verglichen – damit man eine möglichst vollständige Sammlung hat.

Mein Beitrag: dasselbe in Osttirol (Prägraten, Virgen und Kals) zu machen – im Sommer hab ich einzelne Interviews mit Personen mit LW oder forstwirtschaftlichen Hintergrund haben, die Bienen haben oder jagen, die einfach viel in der Natur unterwegs sind und viel beobachten…geführt – dabei hab ich viele Beobachtungen von Umweltveränderungen gesammelt.

Heute geht es darum einen Teil dieser Beobachtungen vom Sommer nochmal gemeinsam zu diskutieren – verschiedene Meinungen zu diesen Veränderungen aus verschiedenen Blickwinkeln (LW, Forst, Imkerei…) zu sammeln und zu ergänzen was für euch fehlt.

Ich habe euch für diese Diskussion eingeladen, weil ihr Personen seid die viel in der Natur unterwegs sind, die alle sich in verschiedenen Bereichen auskennen und die Kals sehr gut kennen/ schon lange hier leben.

3. Kurze Vorstellrund

Mag jede/jeder kurz 2-3 Sätze zu sich sagen, bevor wir losstarten? *(Ich starte und gebe an x weiter)*

4. Grundregeln

Also, der Verlauf wird jetzt so sein, dass ich euch die zu besprechenden Beobachtungen zeig und Fragen dazu stellen. Es kann dann einfach Antworten, wem was dazu einfällt, wer was dazu sagen will.

Es geht nicht darum, dass ihr mir einer nach dem anderen die Frage beantwortets, sondern ihr könnt jede Frage gerne miteinander diskutieren – also ergänzen was die anderen sagen, widersprechen, Beispiele bringen! Wichtig ist einfach, dass sich alle an der Diskussion beteiligen können. Es gibt keine richtigen oder falschen Antworten. Ich bin einfach an eurer Meinung, eurer persönlichen Erfahrung interessiert, die ja bei jedem ganz anders sein kann.

Ich bin hier um Fragen zu stellen, zu zuhören und aufzupassen, dass alle die Chance haben zu Wort zu kommen. Was wir besonders beachten müssen ist, dass immer nur einer von euch gleichzeitig redet, sonst funktioniert das online nicht – dann hören wir einander gar nicht mehr.

Ich würde diese Diskussion heute gerne aufnehmen und mir Notizen machen. Die Audioaufzeichnungen werde ich dann verschriftlichen und für meine Arbeit verwenden. Zu diesen Aufzeichnungen habe nur ich Zugang und ich werde sie sicher aufbewahren. Ich werde alles anonymisieren, niemand kann also wissen, wer an der Diskussion teilgenommen hat und wer was gesagt hat. Und es werden auch keine persönlichen Infos weiterverwendet.

Wenn das für euch so in Ordnung ist, dann würd ich die Aufzeichnung jetzt einfach starten?!

→ *Aufzeichnung starten: Teilnehmer*innen müssen auf „zustimmen“ klicken*

Die Diskussion wird maximal 1 1/2 Stunden dauern und ich würde Vorschlagen, dass wir in der Hälfte eine 10 Minuten kurze Pause machen.

Wenn jemand während der Diskussion nichts mehr hört oder ihr sonst ein Problem habt, dann könnt ihr (a) in den Chat schreiben, oder (b) nochmal auf den Link klicken und euch neu einloggen, oder (c) ihr ruft mich am Telefon an, dann findet wir gemeinsam eine Lösung.

4. Gruppendiskussion:

Ich teile jetzt den Bildschirm mit euch, damit ihr die jeweilige Umwelt- und Klimaveränderung und meine Fragen dazu vor euch auf dem Bildschirm sehen könnt.

→ *Könnt ihr jetzt alle meine Präsentation sehen?*

→*Seht ihr auch mein und die Videos von allen anderen?*

Links seht ihr jetzt immer eine beobachtete Veränderung die ich mit euch besprechen will. Rechts scheinen dann eine nach der anderen Frage dazu auf – einfach damit wir alle einen Überblick haben wo wir gerade sind.

Frage 1 bis 5 mit jeder zu besprechenden Beobachtung durchgehen

1. **„[Zitat der beobachteten Veränderung]“ – Habt ihr diese Veränderung auch bemerkt/so wahrgenommen/so beobachtet?**
2. **Was denkt ihr sind die Ursachen für diese Veränderung?**
   - Klimawandel: ja/nein
   - Wenn nicht Klimawandel, was dann?
3. **Falls Klimawandel die Ursache ist: Seit wann beobachtet ihr diese Veränderung?**
4. **In welche Richtung geht die Veränderung? / Welchen Trend hat diese Veränderung?**
   - Z. B. seltener/öfter, mehr/weniger, intensiver/schwächer
5. **Hat diese Veränderungen Auswirkungen auf euch, euren Haushalt oder die Gemeinde? Wenn ja, könnt ihr sie genauer beschreiben?**
6. **Gibt’s noch andere Veränderungen, die euch einfallen, über die wir noch nicht gesprochen haben, die euch wichtig erscheinen?**

   → Wenn ja: Frage 2-5.

Vielen Dank, dass ihr heute an dieser Gruppendiskussion teilgenommen habt und eure Meinung mit allen/mir geteilt habt. Ich hoffe, die Diskussion war auch für euch angenehm.

Check out: persönlicher Abschluss.

11.3. List of change observations for the FGD

Physikalische Systeme

Schneefall und Schneedecke

1. „Es fängt später zu schneien an. Früher gab es schon im November/Dezember Schnee. Jetzt ist grüne Weihnachten schon fast normal"
2. „Es schneit weniger konstant. Es schneit lange nicht/seltener, aber wenn es dann schneit, schneit es sehr viel."
3. „Die Schneegrenze steigt. Es gibt mehr Regen statt Schnee in höheren Lagen."
4. „Weniger Schnee auf dem Gletscher. Die Schneedecke auf dem Gletscher dauert kürzer an"

Eis

5. „Der Boden friert später im Herbst/Winter. Der Boden friert seltener"

Wasser

6. „Wasserstand von Gewässern und Quellen nimmt ab/ist niedriger als früher" vs. „Es gibt keine Probleme mit Wasserknappheit"

Boden

7. „Die Böden sind trockener. Der Boden ist nur oberflächlich feucht und bleibt nicht lange feucht."

Lawinen

8. „Große Lawinen, die eigentlich als Jahrhundertereignisse beschrieben werden, gehen häufiger ab"
9. „Es gibt nicht mehr Lawinen als früher"

Muren

10. „Muren/Erdrutsche gehen schneller und häufiger ab."vs. „Es gibt nicht mehr Murenabgänge als früher"

Hochwasser- und Wildbachereignisse

11. „Es gibt häufiger Hochwasser- und Wildbachereignisse" v.s. „Hochwasser sind nicht häufiger als früher"

Biologische Systeme

Höhenverteilung von wilden Pflanzen

1. „Die Waldgrenze/die Baumgrenze steigt. Bäume wachsen immer weiter hinauf." (v.a. Larix decidua und Pinus cembra, aber auch Betula pendula und Picea abies wurden gennant)
2. „Schwarzer Holunder, Vogelbeeren und Haselnussbüsche wachsen in höheren Lagen"

Wachstum von Pflanzen

3. „Mehr Holzzuwachs im Wald."

4. „Die Vegetation wächst generell besser (wenn es nicht zu heiß ist und genug Wasser gibt)."
5. „Der Wald und die Vegetation leiden unter Trockenheit und Hitze"

Geschwächter Wald

6. „Der Wald ist geschwächt und verwundbarer"
7. „Der Wald ist weniger stabil und weniger widerstandsfähig"

Schädlinge/Krankheiten im Wald

8. „Lärchen haben gelb/orange/braune Nadeln. Die Nadeln werden nicht so grün im Sommer"
9. „Befall mit Lärchenminiermotten hat zugenommen"
10. „Mehr Borkenkäfer bzw. mehr Borkenkäferbefall"
11. „Der Borkenkäfer ist jetzt in Gebieten wo es früher keinen Borkenkäfer gab"

Invasive Pflanzen

12. „Manche invasive Pflanzen breiten sich mehr aus" z.B. Kanadische Goldrute, drüsiges Springkraut, japanischer Knöterich, Riesen Bärenklau

Phänologie von Wildpflanzen

13. „Manche Pflanzen blühen früher. Z.B. Edelweiß (bis zu einem Monat früher), Sal-Weide (Palmkätzchen; teilweise schon zur Weihnachtszeit), Heidelbeeren (bis zu einem Monat früher), Johannisbeeren (bis zu einem Monat früher), Kirschen, Holunder"
14. „Vegetationsperiode ist länger: früheres Austreiben, Wachsen, Reifen"
15. „Manche Pflanzen verblühen schneller/trocknen schneller aus. Z.B. wilde Himbeeren" *(im Zusammenhang mit Tracht der Honigbienen erwähnt)*

Wild

16. „Die Räude breitet sich eventuell mehr aus als früher." v.a. bei Steinböcken
17. „Mehr Infektionen mit Gamsblindheit bei Steinböcken und Gämsen."
18. Die Wildtiere sind gestörter/beunruhigter als früher. Z.B. Das Wild muss häufiger fliehen, Jungtiere stürzen, Elterntiere finden ihren Nachwuchs nicht mehr etc
19. „ Die Rotwild Population hat zugenommen"

Vögel

20. „Man hört generell weniger Vögel - Man sieht z.B. weniger Bachstelzen und Hausrotschänzchen"
21. „Es gibt weniger Schwalben/ Es gibt weniger Rauch- und Mehlschwalben./ Es gibt mehr Rauchschwalben, aber weniger Mehlschwalben."
22. „Es gibt mehr Elstern und Drosseln"

Anthropogene Systeme:

Schädlinge im Grünland

1. „Mehr Schäden durch Junikäfer und/oder Maikäfer"

Almflächen

2. „Almflächen wachsen zu/ verbuschen schneller." Dominante Arten sind z.B. Schwarzerle, Alpenrosen und später Bäume z.B. Lärche, Zirbe, Birke

Weiden und Wiesen

3. „Die Pflanzen-Diversität in Weiden und Wiesen nimmt ab"

Honigbiene

4. „Der Honigertrag sinkt v.a. in niedrigeren Lagen - am Berg ist es besser, da es kühler ist“
5. „Die Bienen schwärmen früher aus – dabei kann der Frost/die Kälte im Frühling ein Problem werden “

<u>Infrastruktur</u>

6. „Mehr Schäden an Gebäuden, Wegenetz etc. Schäden, bedingt durch Extremereignisse (Lawinen, Muren, Hochwasser etc.). Vor allem im Almgebiet.“
7. „Veränderte Wanderwege/routen bzw. manche Wanderwege werden geschlossen, weil es zu gefährlich ist aufgrund von vermehrtem Steinschlag, Felssturz, Schmelzen der Gletscher und des Permafrostes“

<u>Obstbäume</u>

8. „Obstbäume wachsen, blühen und reifen in höher gelegenen Gebieten wo das früher nicht der Fall war.“

11.4. Category systems

11.4.1. Observations of climate and environmental change

Table 16: Category system of observations of climate and environmental change (adapted from Reyes-García et al. 2019)

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
Climatic	Temperature	Mean temperature	Changes in mean temperature Changes in the frequency of warm days Changes in the frequency of cold days Changes in the frequency of sunny days Changes in sunshine intensity Changes in the temperature during the night Changes in the temperature during the day Changes in temperature associated with elevation
		Temperature extremes	Changes in the frequency of heat waves Changes in the frequency of cold waves Changes in the intensity of frost Changes in the frequency of days with extreme temperatures Changes in the duration of heat waves Changes in the strength of heat waves Changes in the length of cold waves Changes in the frequency of frost days
	Precipitation	Mean precipitation	Changes in mean rainfall Changes in number of rainy days Changes in the number of dry days
		Precipitation extremes	Changes in the intensity of heavy rainfall events Changes in the frequency of heavy rainfall events Changes in the frequency of flash floods Changes in the frequency of natural disasters related with rainfall
		Precipitation distribution, variability and predictability	Changes in the frequency of patchy rains Changes in the frequency of dry spells Changes in the predictability of rainfall Changes in variability of rainfall Changes in the duration of rainfall events
		Drought	Changes in the frequency of drought events

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
			Changes in the intensity of drought Changes in the length of drought Changes in the frequency of years without any rainfall
		Clouds and fog	Changes in cloud size Changes in cloud thickness Changes in the number of clouds Changes in the frequency of fog or misty days Changes in the frequency of cloudy days Changes in the duration of fog Changes in the colour of clouds
	Air masses	Wind	Changes in wind strength or speed Changes in the number of windy days Changes in wind direction Changes in wind temperature Changes in the frequency of wind storms Changes in the intensity of wind storms
		Storm (hail storm/dust storm/sandstorm)	Changes in the frequency of lightning and thundering Changes in the frequency of hail storms Changes in the frequency of sand or dust storms Changes in the intensity of hail storms Changes in the intensity of sand or dust storms Changes in the frequency of storms
		Cyclones, tornadoes	Changes in the frequency of cyclones and tornados Changes in the intensity of cyclones and tornados
	Seasonal events	Seasonal ice formation changes	Changes in the speed of ice melting or break-up Changes in the speed of ice formation Changes in the timing of ice melting or break-up Changes in the timing of ice formation Changes in the frequency of freeze events Changes in the duration of ice Changes in ice stability
		Duration and timing of seasons	Changes in the length of seasons Changes in the duration of seasonal events (e.g., monsoon) Changes in the timing (onset or end) of seasons Disappearance of one or more seasons
		Seasonal temperature changes	Changes in the frequency of unusual temperatures in a given season Changes in the mean temperature in a given season Changes in the frequency of extreme winters Changes in the intensity of extreme winters
		Seasonal precipitation changes	Changes in the amount of rainfall in a given season Changes in the intensity of rainfall in a given season Changes in the variation of rainfall in a given season Changes in the timing of rainfall season (onset, end)

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
			Changes in the duration of rainfall season Changes in the timing of dry season (onset, end) Changes in the duration of dry season
Physical	Freshwater physical systems (continental waters)	Mean river flow	Changes in river water flow and volume Changes in river water level Changes in the number of river pools Changes in river water depth Changes in the frequency of dying rivers
		River and lake floods	Changes in the extension of the area flooded by rivers Changes in the frequency of river floods Changes in the intensity of river floods Changes in the extension of the area flooded by lakes Changes in wetland surface
		Fresh water availability/quality	Changes in freshwater quality Changes in freshwater availability Changes in freshwater pollution Changes in freshwater transparency / concentration of dissolved particles Changes in freshwater salinity Changes in taste of snow and freshwater Changes in the number of natural freshwater springs Changes in number of freshwater ponds
		Water temperature of rivers and lakes	Changes in temperature of river water Changes in temperature of lake water
		Lake level	Changes in level of lake water Changes in the duration of temporary lakes Lakes disappearing
		Phreatic/underground water	Changes in the phreatic level Changes in the speed of aquifer recharge
		River bank / pond erosion / sedimentation	Changes in the frequency of river or pond bank erosion Changes in the intensity of river or pond bank erosion Changes in the frequency of river or pond sedimentation Changes in the intensity of river or pond sedimentation Changes in the location of river or pond sedimentation
	Terrestrial physical systems (Soil & land)	Soil erosion/landslides	Changes in rain-induced soil erosion and soil loss Changes in soil sedimentation Changes in wind-induced soil erosion and soil loss Changes in the frequency of landslides Changes in the intensity of landslides Changes in soil texture Changes in soil desertification
		Soil moisture	Changes in soil humidity, dryness

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
			Changes in soil evaporation Changes in soil water infiltration
		Soil temperature	Changes in soil temperature
		Edaphic properties (fertility, structure and biology)	Changes leading to soil degradation Changes in soil fertility Changes in soil productivity Changes in soil biota
		Earthquake and tsunamis	Changes in the frequency of earthquakes and tsunamis Changes in the intensity of earthquakes and tsunamis
	Cryosphere (Ice & snow)	Snowfall and snow cover	Changes in the amount of snowfall Changes in variability of snowfall Changes in the frequency of snowfall Changes in the depth of snow Changes in the physical structure and texture of snow Changes in the length of temporary snowcover Changes in the extent of permanent snow
		Ice sheet / Lake and river ice	Changes in the physical structure and texture of ice in lakes or rivers Changes in the thickness of ice in lakes or rivers Changes in ice melting or breaking patterns in lakes or rivers
		Glaciers	Changes in the extension of glaciers Changes in the movement of glaciers
		Permafrost	Changes in the extent of permafrost surface Changes in the continuity of permafrost surface Changes in the depth of the permafrost layer Changes in the thawing or melting of permafrost
		Sea ice	Changes in the extent of sea-ice surface Changes in the thickness of sea-ice
	Climate-induced natural hazards [8]	Avalanches	Changes in the type of avalanches Changes in the frequency of avalanches Changes in the intensity of avalanches
		Rockfall	Changes in the frequency of rockfall
		Dynamic flooding	Changes in the frequency of dynamic flooding Changes in the intensity of dynamic flooding
		Mudflow	Changes in the frequency of avalanches Changes in the intensity of avalanches
Biological	Freshwater Wild Fauna	Fresh water spp abundance	Changes in the abundance of freshwater animal species, excluding fish (mammals, birds, amphibians, reptiles, crustaceans, etc) Changes in the abundance of freshwater plant species Changes in the abundance of freshwater fish Disappearance of freshwater species
		Fresh water spp composition	Change in the species composition of freshwater species
			Changes in the distribution of freshwater species

[8] The subsystem „climate-induced hazards" and the related codes and subcodes were added during the coding process.

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
		Fresh water spp habitat range (distribution)	Changes in freshwater species migration areas and routes
		Fresh water spp invasive allien species	Changes in the abundance or occurrence of freshwater species stated as invasive
		Fresh water spp disease/pest/mortality	Changes in the size of freshwater animal species Changes in the frequency of diseases in freshwater animal species Changes in the frequency of malformations freshwater animal species Changes in the frequency of parasites in freshwater animal species Changes in the mortality of freshwater animal species
		Fresh water spp phenology	Changes in the behaviour of freshwater animals Changes in the timing of migration of freshwater animal species Changes in the timing of mating or reproduction of freshwater animal species
		Fresh water spp reproduction	Changes in freshwater species´ reproduction effectiveness Changes in the number of eggs, pups or offspring of freshwater species
		Fresh water spp quality	Changes in the taste of freshwater animal species
	Terrestrial Wild Fauna	Terrestrial fauna abundance	Changes in the abundance of terrestrial animals (mammals, birds, reptiles, insects, etc) Disappearance of terrestrial animal species
		Terrestrial fauna composition	Change in the species composition of terrestrial fauna
		Terrestrial fauna habitat range (distribution)	Changes in the distribution of terrestrial animal species Changes in terrestrial animal species migration areas and routes
		Terrestrial fauna invasive alien species	Changes in the abundance or occurrence of terrestrial animal species stated as invasive (cockroaches, rats, pigeons, etc.)
		Terrestrial fauna disease/pest/mortality	Changes in the frequency of terrestrial animal diseases Changes in the frequency of animal pest-vector borne diseases (flies, ticks, etc) Changes in the frequency of malformations in terrestrial animals Changes in the size of terrestrial animals Changes in the mortality of terrestrial animals
		Terrestrial fauna phenology	Changes in the occurrence of unusual behaviour of terrestrial animals Changes in the timing of migration of terrestrial animal species Changes in the timing of mating, reproduction or hibernation of terrestrial animal species Changes in the behaviour of insects
		Terrestrial fauna reproduction	Changes in terrestrial animal species´ reproduction effectiveness Changes in the number of eggs, pups or offspring of terrestrial animal species

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
		Terrestrial game spp quality	Changes in the taste of terrestrial animal species
	Terrestrial wild flora (fungi-plants-shrubs-trees)	Wild flora abundance (excluding timber and NTFP)	Changes in the abundance of wild plant or fungi species Changes in the density of wild plant or fungi species Changes in the type of vegetation Disappearance of wild plant or fungi species Changes in the number of species of wild plants or fungi
		Wild flora composition	Change in the species composition of wild flora
		Wild flora habitat range (distribution)	Changes in the distribution of wild plant or fungi species
		Wild flora invasive alien species	Changes in the abundance or occurrence of wild plant or fungi species stated as invasive
		Wild flora disease/pest/mortality	Changes in wild plant or fungi species mortality
		Wild flora phenology	Changes in wild plant species flowering time Changes in wild plant or fungi species fruiting time Changes in wild plant species´ timing of leaf shedding or growing new leaves
		Wild flora productivity and quality	Changes in vegetation height Changes in wild plant species height Changes in the growth rate of wild plant species Changes in the productivity of wild plant species Changes in the size of wild fruits Changes in recruitment (younger individuals growing into large size classes)
		Timber forest sp. composition and structure	Changes in forest cover Changes in timber species composition Changes in the density of timber species
		Timber forest sp. availability and quality	Changes in the abundance of timber species Disappearance of timber species Disappearance of useful woody species Changes in the growth rate of timber species
		Non-timber forest products availability and quality	Changes in the taste of wild fruits Changes in the abundance of wild fruits Changes in the abundance of other edible products Changes in the abundance of medicinal plants
	Land cover change	Habitat degradation	Habitat degradation Landscape change Biodiversity loss Landscape disappearance Changes in ecosystem productivity Loss of specific landscape elements Habitat fragmentation
		Forest fires	Changes in wildfire frequency Changes in intensity of wildfires
Human	Aquaculture (marine and fresh water)	Aquaculture productivity and quality	Changes in productivity in aquaculture Changes in size of animals in aquaculture Changes in taste of animals in aquaculture
		Aquaculture disease/pest/mortality	Changes in frequency of animal disease in aquaculture

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
			Changes in the frequency of animal malformations in aquaculture Changes in the frequency of parasites in aquaculture Changes in mortality rates in aquaculture
		Aquaculture phenology and reproduction	Changes in the occurrence or frequency of unusual animal behaviour in aquaculture Changes in the time of mating or reproduction in aquaculture Changes in the effectiveness of animal reproduction in aquaculture Changes in the number of eggs, pups or offspring in aquaculture
	Cultivated plant spp (crops, orchards)	Cultivated spp productivity and quality	Changes in crop productivity / yield Changes in cultivated species´ fruit size Changes in the frequency of successful cropping seasons Changes in crop growing patterns
		Seed or propagule availability or quality	Changes in the availability of crop seeds
		Disease/pest/mortality of crops	Changes in the frequency of crop diseases (virus, fungi, bacteria, nematodes, etc) Changes in the frequency of crop ´pests´ (insects, birds, larvae, etc) Changes in crop mortality rates
		Crop weed (invasive alien species)	Changes in the frequency or occurrence of weed species stated as invasive
		Phenology and reproduction	Changes in crop flowering time Changes in crop fruiting time Changes in crop maturation time Changes in crop harvesting time Changes in crop sowing / planting time Changes in length of crop flowering time Changes in length of crop fruiting time Changes in length of crop maturation time Changes in length of crop harvesting time Changes in crop suitable cultivation areas
	Pastures and grasslands	Pasture availability and productivity	Changes in pasture cover, surface or abundance Changes in pasture productivity Degradation of rangeland vegetation Changes in pasture species´ growth rate
		Pasture spp composition, distribution and quality	Changes in the number of pasture species Changes in the composition of pasture species Disappearance of pasture species Changes in the abundance of specific pasture species
		Pasture disease/pest/mortality	Changes in the frequency of diseases in pasture species Changes in the frequency of ´pests´ in pasture species (insects, larvae, etc) Changes in pasture mortality rates
		Pasture weed (invasive alien species)	Changes in the frequency or occurrence of species stated as invasive in pastures

System	Subsystem	Code (Impacted element/process)	Subcode (LICCI)
			Changes in the abundance of plant species in pastures that are toxic or unpalatable for livestock
		Pasture phenology and reproduction	Changes in pasture species´ timing of vegetative growth
			Changes in pasture species´ timing of reproduction
			Changes in pasture seed availability
	Livestock	Livestock productivity and quality	Changes in livestock productivity (e.g., milk, meat, wool)
			Changes in the milking period of livestock
		Livestock spp composition	Changes in the species composition of livestock
		Livestock disease/pest/mortality	Changes in the frequency of livestock disease
			Changes in livestock mortality
			Changes in the frequency of livestock pest-vector borne diseases (flies, ticks, etc)
			Changes in the frequency of parasites in livestock
		Livestock phenology and reproduction	Changes in the effectiveness of livestock reproduction
			Changes in the frequency of livestock mating
			Changes in the timing of livestock mating or reproduction
			Changes in the number of pups or offspring in livestock
			Changes in livestock behaviour
	Human health	Diseases	Changes in the incidence of human diseases (e.g., flu, allergies, malaria, etc)
		Health injuries, physical affection	Changes in the incidence of human health injuries (e.g., ice-related accidents, weather inclemency, walking longer distances to water)
		Hunger	Changes in the frequency of hunger
			Changes in the number of people affected by hunger
		Conflicts	Changes in the frequency of conflicts over pastures
		Cultural/spiritual/identity values	Changes in cultural-identity-spiritual values
	Infrastructure	Transport (e.g. trails)	Changes in frequency of problems with transportation
		Mountain path networks[9]	Changes in the extent of damaged hiking paths
			Changes in the accessibility of hiking paths or mountain tours
Category		**Subcode**	
Type of observation		Climate change related driver	
		Not climate change related driver	
		One-time events	

11.4.2. Climate change adaptations

[9] The code „mountain path networks" and the related subcodes were added during the coding process.

Table 17: Category system of climate change adaptations (adapted from Schlingmann et al. (2021))

Sector	Domain	Class
Crop and tree cultivation (incl. fodder)	Livelihood organisation	Livlihoods (sub) system
		Size, structure & composition
		Timing
		Infrastructure, construction & technology
		Mobility & Location
	Livelihood related activities	Seeding/Planting
		Soil management
		Weeding & Pesticide demand
		Fertilizer demand
		Water demand
		Storage
		Safety behaviour
Livestock rearing/ Animal husbandry	Livelihood organisation	Livlihoods (sub) system
		Size, structure & composition
		Timing
		Infrastructure, construction & technology
		Mobility & Location
	Livelihood related activities	Feed demand
		Animal health
		Water demand
		Storage
		Safety behaviour
Hunting/ Gathering	Livelihood organisation	Livlihoods (sub) system
		Size, structure & composition
		Timing
		Infrastructure, construction & technology
		Mobility & Location
	Livelihood related activities	Storage
		Safety behaviour
Household capacities	Household organisation	Financial capital
		Physical capital (incl. Infrastructure, construction & technology)
		Natural capital
		Human capital
		Social capital
		Timing
		Mobility & Location

	Household related activities	Food demand
		Human health
		Water demand
		Other household resource demand
		External resource dependencies
		Storage
		Safety behaviour