Publizierbarer Endbericht

gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	STELLA
Langtitel:	**St**orylines of Socio-**E**conomic and C**l**imatic drivers for **L**and use and their hydrological impacts in **A**lpine Catchments
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	Partner 1: Institut für Soziologie, Universität Innsbruck, Tirol (Univ.-Prof. Dr. Markus Schermer) Partner 2: Institut für Meteorologie, Universität für Bodenkultur, Wien (Assoz. Univ.-Prof. Dr. Herbert Formayer)
Schlagwörter:	Kombinierte Landnutzungs- und Klimaänderung, Storylines, Schneehydrologische Modellierung
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B) Projektübersicht

1 Kurzfassung

Globale Klimaszenarien basieren auf angenommenen Entwicklungen der sozioökonomischen Rahmenbedingungen, der Landnutzung und der daraus resultierenden Treibhausgasemissionen. Die Entwicklung der lokalen sozioökonomischen Situation und Landnutzung kann jedoch von den globalen Szenarien abweichen, in Abhängigkeit von unterschiedlichen natürlichen (z.B. Klimabedingungen, Relief) und gesellschaftlichen (z.B. kultureller und politischer Rahmen) Bedingungen. Da die aktuelle Landnutzung und ihre zukünftige Entwicklung den Wasserkreislauf und die Abflussreaktion der Einzugsgebiete auf Niederschlagsereignisse stark beeinflussen, ist es für das Management von Wasserressourcen, Wasserkraftnutzung und Hochwasserrisikoabschätzung unabdingbar, über Wissen über zukünftige Landnutzungsentwicklungen und die resultierenden hydrologischen Auswirkungen zu verfügen. Darüber hinaus können wichtige Erkenntnisse für das Landnutzungsmanagement selbst gezogen werden, wenn Auswirkungen möglicher zukünftiger Strategien auf den Wasserhaushalt bekannt sind.

Im Rahmen des Projekts *STELLA* wurden die Auswirkungen von Landnutzungsänderungen in Wäldern untersucht, weil Änderungen im Forstmanagement langfristige Auswirkungen zeigen, deren Zeitskala mit jener von Klimaänderungen übereinstimmt. Darüber hinaus zeigen verschiedene Waldbesitzer, von Einzelpersonen bis zu staatsnahen Organisationen (Österreichische Bundesforste) eine Vielzahl an unterschiedlichen Interessen bezüglich Waldnutzung und -management. Schließlich haben mögliche Änderungen in Waldwachstum und –management signifikante Auswirkungen auf die hydrologischen Eigenschaften der Einzugsgebiete.

STELLA zielte daher darauf ab, Akteuren aus dem Bereich der Landnutzungsplanung und dem Wasserressourcenmanagement eine Entscheidungsgrundlage zu liefern. Dazu wurden die hydrologischen Auswirkungen der gekoppelten Änderung von Klima und sozio-ökonomischen Bedingungen untersucht. Gekoppelte Handlungsstränge der klimatischen und sozioökonomischen Entwicklung wurden generiert, aus denen in einem späteren Schritt verschiedene Landnutzungsentwicklungen abgeleitet werden konnten. Dabei wurden sowohl globale Klimaentwicklungen mit den zugehörigen Landnutzungsszenarien berücksichtigt als auch regionale Besonderheiten und Abweichungen der Landnutzungsentwicklung. Als Untersuchungsgebiet wurde ein repräsentatives alpines Einzugsgebiet, jenes der Brixentaler Ache in Tirol mit drei benachbarten Teileinzugsgebieten gewählt. Während Szenarien für die globale Skala üblicherweise durch die wissenschaftliche Gemeinschaft entwickelt werden, stellen die *STELLA* Handlungsstränge verschiedene Kombinationen der räumlich und zeitlich verfeinerten Klimaszenarien mit sozioökonomischen Trends auf lokalem bis regionalem Maßstab dar.

Die Ziele von *STELLA* waren daher, (i) gemeinsam Handlungsstränge der klimatischen und sozioökonomischen Entwicklung auf verschiedenen räumlichen und zeitlichen Skalen zu entwickeln, die in verschiedenen Landnutzungsmustern resultieren, (ii) deren hydrologische Auswirkungen zu modellieren, evaluieren und illustrieren und (iii) die simulierten möglichen zukünftigen hydrologischen und sozioökonomischen Auswirkungen für die Akteure zu übersetzen und kommunizieren.

Um diese Ziele zu erreichen, wurde folgender Arbeitsablauf durchgeführt, unterteilt in siebe Arbeitspakete (**AP**): **AP 1** war dem Projektmanagement gewidmet. Im **AP 2** wurden die hydro-klimatologischen Daten aus Vergangenheit, Gegenwart und Zukunft für die Modellierung aufbereitet. Außerdem wurde Feldarbeit durchgeführt, um die räumliche Variabilität der meteorologischen Bedingungen und Schneedeckenentwicklung innerhalb und außerhalb der Waldbereiche zu beobachten. Im **AP 3** wurde das Niederschlags-Abflussmodell WaSiM um ein Submodell erweitert, das die Schneeakkumulationsprozesse innerhalb des Waldes und seine Auswirkungen auf die meteorologischen und hydrologischen Bedingungen besser abbilden kann. Ziel des **AP 4** war die Erhebung von Informationen über die sozioökonomischen Einflussfaktoren auf das Waldmanagement für die Entwicklung der Handlungsstränge auf der Grundlage von Experteninterviews sowie eines Fragebogens, der an die Waldbesitzer im Untersuchungsgebiet verteilt wurde. Im AP 5 wurden die gekoppelten Handlungsstränge, die in mögliche zukünftige Landnutzungsentwicklungen münden, ausgearbeitet. Dazu wurde eine transdisziplinäre Diskussion in einem ersten Akteursworkshop durchgeführt. In einem zweiten Schritte wurden daraus transiente Landnutzungskarten abgeleitet. Sie bildeten die Grundlage für die hydrologische Simulation mit der erweiterten Version von WaSiM im **AP 6**. Die Ergebnisse wurden im **AP 7** gemeinsam evaluiert. Die wissenschaftlichen Ergebnisse wurden im Anschluss im Rahmen eines zweiten Akteursworkshops übersetzt, um mögliche zukünftige Entwicklungen und deren Auswirkungen auf die hydrologischen und sozioökonomischen Bedingungen zu zeigen.

Die Ergebnisse von STELLA beziehen sich auf drei verschiedene Ebenen: (i) im Bereich der Sozialwissenschaften wurden plausible und konsistente Handlungsstränge zukünftiger Landnutzungsentwicklungen für das Brixental in Abstimmung mit Klimaszenarien und mit Hilfe eines transdisziplinären Akteursprozesses erzeut. (ii) Im Bereich der Naturwissenschaften wurde das physikalisch-basierte Modell WaSiM um ein Schnee-Interzeptionsmodul erweitert, um die temporäre Speicherung von Schnee innerhalb des Waldes zu berücksichtigen, den Prozess der Interzeption und Sublimation zu quantifizieren und die modifizierte Entwicklung der saisonalen Schneedecke auf dem Waldboden besser zu simulieren. (iii) Als integrative Synthese wurden die gemeinsam entwickelten Handlungsstränge mit Klimaszenarien (A1B und RCP 8.5) kombiniert und ihre Auswirkungen auf die Komponenten des Wasserhaushalts untersucht.

In sechs Modelldurchläufen wurde der Wasserhaushalt des Brixentals für die drei Handlungsstränge ökologische Anpassung (A), ökonomische Übernutzung und Verwilderung (B) sowie Rückzug und Verwilderung (C), jeweils kombiniert mit den Klimaszenarien A1B und RCP 8.5 bis 2100 simuliert. Die prognostizierte Temperaturerhöhung beträgt bis dahin 3°C für A1B, 8°C für RCP 8.5. Die Niederschlagssumme ändert sich nur im RCP 8.5-Szenario, mit einer Abnahme in der Größenordnung von 20% wird für das Untersuchungsgebiet gerechnet. Die Abflussmenge liegt für die A1B-Zukunft (2070-2100) zwischen 25% (A) und 35% (C) unterhalb jener des Referenzzeitraums (1981-2005), im RCP 8.5-Szenario beträgt die Abnahme 65% (A) bis 75% (C). Die Hauptursache für die Reduktion des Abflusses liegt in der Erhöhung der (monatlichen) Evapotranspiration bis zu 20% (A1B) und 25% (RCP 8.5) für gleichbleibende Landnutzung, für die Handlungsstränge mit stark wachsenden Waldflächen (B und C) steigt die Evapotranspiration auf fast 30% (A1B) bis über 35% (RCP 8.5). Das Waldwachstum in Handlungsstrang C führt zu einer Abnahme des Jahresabflusses um 13% (A1B) bzw. 25% (RCP 8.5). Die Abnahme des monatlich akkumulierten Schneewasseräquivalents liegt zwischen 50% (A) und 70% (C) bei A1B und beträgt teilweise mehr als 90% bei RCP 8.5.

2 Executive Summary

Simulations of global future climate are based on assumed developments of socio-economic framing conditions, land use and resulting greenhouse gas emissions. The development of local socio-economic patterns and land use, however, may deviate from the global scenarios depending on a variety of natural (e.g. climatic conditions, topography) and societal (e.g. cultural and political framework) conditions. As land use and its development strongly control the water cycle and runoff response of catchments to precipitation events, knowledge about future land use development and the resulting hydrological impacts is indispensable for the management of water resources, hydropower generation and flood risk assessment. On the other hand, important conclusions for land use management itself might be drawn if the effects of any of the potential future strategies on the water supply are known. The project *STELLA* specifically focuses on the impact of land use changes in forested areas because changes in forest management have long term impacts which comply with the time scale of climatic changes. Furthermore the different forest owners, from single individuals to the federal forest administrations (Österreichische Bundesforste), show a plethora of different interests in forest use and management. Finally, potential changes in forest growth and management will have significant impacts on the hydrological conditions.

STELLA aimed at providing a basis for decision making for stakeholders from land use planning and water resources management by investigating the hydrological impacts of combined changing climatic and socio-economic conditions. Coupled climate and socio-economic storylines that result in different land use developments were generated, thereby considering both the global climate with respective land use scenarios as well as regional peculiarities and deviations of land use development. The chosen test site, a representative Alpine catchment, is the one of the Brixentaler Ache in Tyrol with three adjacent subcatchments. While scenarios are developed by the research community usually for the global scale, the *STELLA* storylines represent different combinations of downscaled future climate scenarios and socio-economic trends at the local to the regional scale.

Consecutively, the **aims** of *STELLA* are (i) to jointly generate storylines of climatic and socio-economic development at different spatial and temporal scales that result in specific land use patterns, (ii) to model, evaluate and illustrate their hydrological effects and (iii) to translate and communicate the simulated potential future hydrological and socio-economic consequences to stakeholders.

To pursue these aims *STELLA* the workflow was divided into the following seven work packages (**WP**s): **WP 1** covered tasks related to the project management. **WP 2** was dedicated to hydro-climatological data preparation (for the past, present and future scenarios) for the modelling; it also included field work to monitor the spatial variability of the meteorological conditions and snow distribution in- and outside the forest canopy. In **WP 3** the model WaSiM was extended with a snow-canopy submodel for a better representation of inside-forest processes and its consequences on meteorological and hydrological conditions. The objective of **WP 4** was to elicit knowledge on socio-economic drivers of changes in forest management for the development of storylines on the basis of a series of expert interviews and the evaluation of a questionnaire provided to all forest owners in the study region. Within **WP 5** coupled storylines resulting in potential future land use evolution were elaborated by means of a transdisciplinary debate in a first stakeholder workshop (using downscaled climate scenarios and trends of future forest management). In a second step the land use scenarios were prepared for transient modelling. In **WP 6** the obtained storylines from WP 5 were used as a basis for simulations of the future hydrological conditions in the study areas using the new, extended version of WaSiM. Within **WP 7** modelling results were jointly evaluated. The scientific findings were illustrated and translated for the stakeholders in a second workshop in order to show potential future conditions and their effects on hydrology and socio-economy.

The results in *STELLA* have been achieved on three different levels of scientific advance: (i) in the domain of social sciences, we have developed plausible and consistent storylines of potential future land use development, harmonized with scenarios of future climate, for the Brixental in a transdisciplinary stakeholder process; (ii) in the domain of natural sciences, we have further extended the physically based hydrological model WaSiM with a snow-canopy interception module to consider the temporal storage of snow inside a forest and quantify the processes of interception and sublimation as well as to better simulate the modified evolution of the seasonal snowpack on the forest ground; (iii) as integrative synthesis, we have combined the jointly developed storylines with scenarios of future climate evolution according to the A1B and RCP 8.5 emission pathways and simulated their combined effects on the components of the catchment water balance.

In six modelling experiments, we have simulated the water balance of the Brixental catchment for the three storylines ecological adaptation (A), economical overexploitation and wildness (B), and withdrawal and wildness (C), each combined with both A1B and RCP8.5 future climatic conditions, until 2100. Projected temperature increase until then for A1B is 3 degrees Celsius, for RCP8.5 it is 8 degrees Celsius. Respective precipitation change only occurs in the RCP8.5 future, and is a decrease in the order of 20%. Annual runoff amount for the A1B future (2070-2100) is 25% (A) to 35% (C) below the reference (1981-2005), for RCP8.5 it is 65% (A) to more than 75% (C). The main reason for the extraction of water from the water balance is the increasing (monthly) evapotranspiration of up to 20% (A1B) to 25% (RCP8.5) for constant land use, and for storylines with strongly growing forests B and C it amounts to almost 30% (A1B) to more than 35% (RCP8.5). The growing forest in storyline C leads to a decrease in annual runoff of 13% (A1B) and 25% (RCP8.5), respectively. Reduction of monthly accumulated snow is between 50% (A) and 70% (C) in A1B, and partly more than 90% in RCP8.5.

3 Background and project aims

Simulations of global future climate are based on assumed developments of socio-economic frame conditions, land use and resulting greenhouse gas emissions leading to IPCC SRES (Special Report on Emission Scenarios) climate scenarios (Nakicenovic and Swart 2000) and RCPs (representative concentration pathways) (van Vuuren et al. 2011). However, the development of local socio-economic patterns and land use may deviate from global scenarios depending on a variety of natural (e.g. climatic conditions, topography) and societal (e.g. cultural and political framework) factors. As land use and its development over time strongly control water cycle and runoff response of catchments to precipitation events, knowledge about future land use development and the resulting hydrological impacts is indispensable for flood risk assessment, planning of water supply and operating of hydroelectric power stations.

Options for land use are basically determined by natural frame conditions such as topographic, geological and soil characteristics. Climatic conditions control, which kind of plants may grow. Climate changes may thus lead to land use changes e.g. to the shifting of tree lines (Köplin et al. 2013). Within the natural frame conditions different types of land use are possible. Socio-economic factors and the development of new technological solutions control which land use type will effectively develop. Thus changes in socio-economic frame conditions and technological changes may have effects on a shorter term than changes of natural conditions due to climate change. Major influencing factors for agricultural and forest land uses are the availability of labor and the possibilities to substitute it by technical solutions. Besides, developments outside agriculture and forestry have to be taken into account. The rise of the tourism industry, especially the impact of land based tourism activities, like for instance alpine skiing, had a substantial impact on land use changes. While the establishment of lifts and skiing slopes have a direct impact on the landscape, the availability of new sources of income influences the viability of farming and forestry and thus indirectly again land use. Tyrol, where only 13% of the land area can be used for settlement, industry, traffic and infrastructure, is prone to overlapping uses and resulting conflicts. Developments in other sectors impact directly or indirectly on land use in agriculture and forestry through competition for labor or changing patterns of demand for products like food, timber or energy (Tasser et al. 2012).

Objectives of the project

STELLA aims at providing a basis for decision for stakeholders dealing with land use planning and flood prevention by investigating the hydrological impacts of changing climatic conditions and socio-economic patterns. Within the project storylines of coupled socio-economic and climatic drivers that result in land use patterns will be developed considering both, the global climate and land use scenarios as defined in the SRES and RCPs as well as potential regional peculiarities and deviations of land use development that result from the special natural and socio-economic setting in a representative Alpine catchment. While scenarios are developed by the research community at a global scale (Moss et al. 2010; van Vuuren et al. 2011), the storylines to be defined in *STELLA* represent different combinations of downscaled future climate scenarios and socio-economic trends at the regional scale.

The research focuses specifically on the impact of land use changes in forests. This focus was selected for a number of reasons:

- Changes in forest management have long term impacts, which comply with the time scale of climatic changes.

- The composition of forest owners comprises farmers (full time and part time) non farming individuals, farmers associations (Agrargemeinschaften) and federal forest administration (Bundesforste), thus there is a plethora of different interests in forest use and management.
- Furthermore the forested area is constantly growing at the expense of marginal agricultural land. Growth of area and potential changes in management will have significant impact on hydrological conditions.

Consecutively, the **aims** of this research project are

i) to jointly generate storylines of climatic and socio-economic development at different spatial and temporal scales that result in specific land use patterns,

ii) to model, evaluate and illustrate their hydrological effects and

iii) to translate and communicate the simulated potential future hydrological and socio-economic consequences to stakeholders.

These **aims** are reached by answering the following research questions:

- Which changes in the regional climatic conditions result from a combined dynamical and statistical downscaling of climate scenarios (SRES and RCPs)?
- Which regional land use changes are likely to coincide with these altered climatic conditions considering both the global developments underlying the SRES and RCPs as well as regional peculiarities and deviations that result from the particular natural and socio-economic setting (e.g. agricultural support systems, tourism development, forestry guidelines etc.)?
- What are the hydrological consequences of these coupled climate and socio-economic storylines?

4 Project content and results

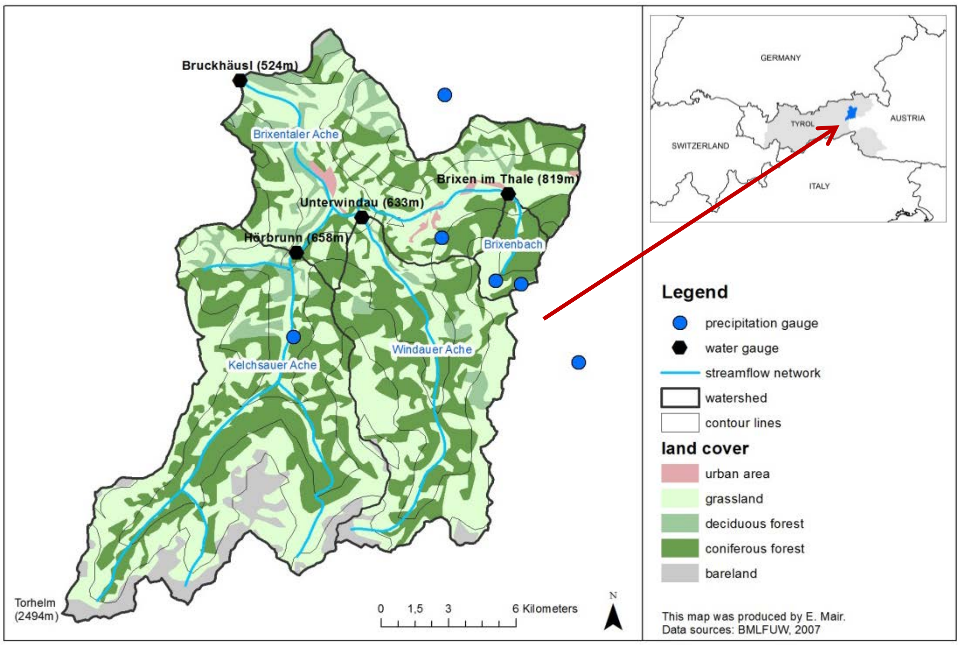

Fig. 1: The catchments Brixentaler Ache, Kelchsauer Ache, Windauer Ache and Brixenbach with precipitation and discharge gauges (operated by the Hydrographic Service of Tyrol).

As study area for the project a catchment-ensemble was chosen in order to answer the research questions for different spatial scales. Fig. 1 shows the catchment Brixentaler Ache (322 km², discharge gauge at Bruckhäusl) with the adjacent subcatchments of the Kelchsauer Ache (134 km², discharge gauge at Hörbrunn), the Windauer Ache (82 km², discharge gauge at Unterwindau) and the Brixenbach (9 km², discharge gauge at Brixen im Thale). These runoff gauges as well as several precipitation gauges are operated by the Hydrographic Service of Tyrol. The discharge gauges Hörbrunn and Bruckhäusl are influenced by small water power plants, indicating the economic importance of water in the catchment (Abteilung VII 3 – Wasserhaushalt im BMLFUW 2012). The selection of these catchments is based on the following facts:

- Brixental is a representative Alpine catchment, intensively used (forestry, pasturing, tourism, water power), thus numerous stakeholders are affected.
- Parts of the study area have already been investigated in pre-projects of the project partners (e.g. ACRP project *SeRAC-CC*). Data, insights and contacts are hence already available to be built upon in *STELLA*.
- The proposed research activities in the area synergetically interlink with other research projects thus creating mutual benefits and added values (e.g., with the alpS research project portfolio http://www.alp-s.at).
- The ensemble of catchments of different size allows investigating hydrological scale effects.

The catchment of the Brixentaler Ache with its subcatchments is situated north of the main ridge of the Eastern Alps in the Greywacke Zone (highest point of the catchment: Torhelm with 2494 m a.m.s.l., lowest point: water gauge at Bruckhäusl 525 m a.m.s.l.). It is dominated by forests and grassland. Settlements are concentrated in the main valley between Bruckhäusl and Brixen im Thale. Regarding natural environment and land use, they represent typical Alpine catchments in mid elevations. Today, forest covers 43 % of the Brixental catchment (BMLFU 2007). Due to the extensification of Alpine pastures, forest re-growth can be observed in many areas (Tasser et al. 2007). The proportion of the total forest land area in Tyrol has increased from the 60s to today by almost 3 % and is currently 41.2 %. Since the 60s the forest area in Tyrol is growing annually by approximately 800 ha (Tiroler Landesregierung 2013). This is mainly due to the effects of socio-economic change in agricultural land use: while fields in the valley, where machinery can be used, are cultivated more intensely, hillsides and mountain areas requiring manual labor are abandoned of agricultural use and reforested. The effects of climate change and agricultural extensification of marginal land accelerate this process also above the (former) tree line. Thus the largest increase of forest is observed in the subalpine and alpine regions. There is growing interest in forests as a resource for renewable energy production and in timber as a natural construction material. This development is also indicated by the increase of 1.5 million cubic meters of wood harvested volumes per year (Tiroler Landesregierung 2013).

On an individual level the forest is still an economic resource for farms and even private households which can be activated if needed. Parallel to the rise in timber harvesting an increase of the stock in the forest is observable. It indicates that the potential earnings of the resource forest are not yet fully utilized. In excess to the present 1.5 million cubic meters per annum, about 1.7-1.8 million cubic meters of timber could be extracted sustainably from Tyrolean forests. As forestry makes an important contribution to the income of agricultural forestry owners (Tiroler Landesregierung 2013), it takes on a new strategic importance within the overall system of an agricultural enterprise and the resilience of a farm system and even for a region. Furthermore forest ownership is changing. In former times, mainly farmers and associations of farmers (besides the federal forest administration - Bundesforste) were forest owners. Nowadays, however, owners are not necessarily actively engaged in agriculture anymore but as descendants became owners via heritage. They obviously have a different interest in forestry than full time farmers.

From a hydrological point of view, the presence/absence of forest affects the local micrometeorological conditions (Liston and Elder 2006) and in consequence the hydrological behavior of the catchment, mainly with respect to modified snow cover dynamics, soil moisture conditions as well as evapotranspiration and runoff generation (De Roo et al. 2001). Forests reduce surface runoff, depending on the age of the forest (Hümann et al. 2011). Hence, the land use developments elaborated in this project focus on potential changes in forested areas (forest extent, forest stand, forest age, forest type) considering different socio-economic factors like political decisions (support systems and regulations), ownership and forms of utilization of timber.

Activities performed within the framework of the project, including methods employed

Description of the results and project milestones (also on work package basis)

WP1 Project Management

The objectives of this work package are the coordination of the project to guarantee the achievement of the project objectives/milestones in time and with high quality. Thus, a cooperative communication structure between all project partners was established to supervise the project, its process (milestones and dates) and budget. Several consortium workshops were held to discuss the interim results and next steps (13th August 2014, 28th September 2015, 26th January 2016, 4th April 2016, 2nd March 2017). The subcontractor CCCA Service Centre fostered and fulfilled the dissemination intensions as described in the assigned section. In close collaboration with the CCCA, a project folder was prepared (milestone 1.1) which was distributed at meetings/presentations. A website for the project was created (www.uibk.ac.at/geographie/stella) and continuously updated with all project information, news and insights both in German and English.

Two stakeholder workshops (milestone 1.2) were carried out in Kirchbichl (between the Brixental and Innsbruck), organized by the CCCA Service Centre (subcontractor of the applicant) in close collaboration with the project partners. The first stakeholder workshop took place on 25th November 2015. There, regional and local stakeholders from agriculture and forestry, tourism, politics, hydrography and regional management critically reviewed the storylines of socio-economic and climate scenarios, which have been prepared by project partner 1 (UIBK SOCIO) and project partner 2 (BOKU MET), regarding their plausibility and consistence. The results and implications of the stakeholder workshop were discussed in follow-up meetings of UIBK GEO and UIBK SOCIO as well as with experts of the regional forest administration.

During the second stakeholder workshop on 30th May 2017 the project results were presented to and discussed with those stakeholders who were ready to take part in the discussion process a second time. On the one hand transient land use maps showing possible developments for different socio-economic scenarios, on the other hand graphics showing the hydrological effects of the combined storylines of climate and land-use development were presented and discussed.

Additionally, dissemination and publication activities were performed in form of scientific papers, oral presentations and posters (milestone 1.3, detailed list see chapter 2.5).

For the public and the stakeholder community in particular, we formulated a one-page document as “executive summary” with the most important hydrological consequences of the combined climate/land use storylines for the Brixental (in German). This document was distributed by the CCCA service centre to the stakeholders who participated in the joint storyline development process (milestone 1.4).

As outreach measure to the public, we also have disseminated the key project results via the press department of the University of Innsbruck. For that purpose an interview with Univ.-Prof. Dr. Markus Schermer and Univ.-Prof. Dr. Ulrich Strasser was held on 8th November 2017. The press release will be distributed through the common channels of the University press release process (in Tyrol; nationally through the CCCA and APA, as well as through common media in print, radio and TV (ORF)) (milestone 1.5).

WP 2: Hydro-climatological data preparation including field work

The objectives of this work package are the acquisition of data for the environmental conditions in the catchment, installation of SnoMoS (**Sno**w **Mo**nitoring **S**tations), measurement of meteorological and hydrological variables in the study area, mapping of land cover, preparation of all the input data for the hydrological simulations and preparation of the downscaled climate scenarios.

SnoMoS installation, maintenance and read-out (milestone 2.1)

The 10 Snow Monitoring Systems (SnoMoS) were delivered in time by the subcontractor Dr. Stefan Pohl (September 2014). After a site inspection in October 2014 (and obtaining the permission of land owners to install our stations), a set of 12 SnoMoS were installed in the Brixenbach valley in November 2014. One SnoMoS was situated closely to the official station of the Hydrographical Service of Tyrol to serve as a reference station (Talkaser), one at the second precipitation gauge in the valley (Wiegalm), one in the highest elevation in the catchment, and one in a young growing forest. The remaining eight stations were pair-wise installed in open and forested sites (see Fig. 2 and 4). After the snow melt season data from all sensors were collected and the 5 SnoMoS situated in the open were unmounted. 7 of the 12 SnoMoS remained during the whole year in the Brixenbachtal and were regularly maintained. 4 of the 5 SnoMoS situated in the open - unmounted after the first winter due to pasturing - were reinstalled in October 2015, when also additional wildlife cameras and snow poles were installed (belonging to the Institute of Geography, i.e. at no costs for *STELLA*). These time-lapse cameras took photos of the snow poles at defined time steps and thus allowed for reconstructing the evolution of snow depth in time. Most devices properly recorded temperature, humidity, wind speed and shortwave radiation. The recordings of the SnoMoS ultrasonic sensor designed for snow depth observations were subject to strong fluctuations. However, a stable signal could be achieved by additional data processing methods (e.g., aggregation to coarser temporal scales). An analysis of the pictures taken by the wildlife cameras and comparison of the results of the two different observational methods has been carried out, showing a good agreement with an average R^2 of 0,87.

After a detailed quality check and correction, the data helped to better understand the micro-climatic conditions beneath the trees as compared to the adjacent open locations, as exemplarily shown in Fig. 3. The figure displays average hourly values of air temperature recorded at two different sites, each of which equipped with one SnoMoS station mounted in the forest and another one in the open. Inside the forest, the diurnal courses of temperature have smaller amplitudes (higher night-time temperatures and lower maximum afternoon temperature). The data also corroborates the expected lower wind speed and solar radiation values under a forest canopy; on average, wind speed was 54% and incoming solar radiation 81% less under the trees than in the adjacent open. These observations underline the potential of the data to facilitate improved model extensions to simulate snow accumulation and melt in forests more precisely than is possible with (most of) today's hydrological models. Data of the SnoMoS monitoring program was utilized to validate the model extensions addressed in WP 3.

Fig. 2: Installed SnoMoS at the location „Sonnleithof“ in the forest (left) and at the forest site (Talkaseralm, Brixenbachtal) with additional snow poles. Picture taken by wildlife camera on 5th March 2016.

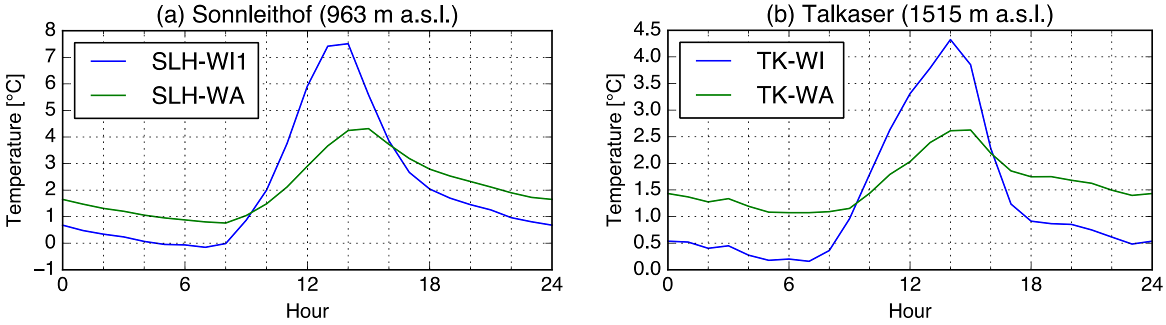

Fig. 3: Average diurnal courses of temperature recorded by SnoMoS stations during the winter season 2015/16. Site (a) Sonnleithof near the outlet of the basin. Site (b) is located at a higher elevation. WI: SnoMoS station in the open, WA: SnoMoS station inside the forest.

Transient land use maps for calibration and validation of the hydrological model (milestone 2.2)

A map of the current land use was generated on the basis of data of the regional government of Tyrol (Landnutzung Tirol 2013, https://www.data.gv.at/katalog/dataset/0eaa80ce-5156-4043-aeab-77f2b24b76b5). As within this dataset the forest areas are not distinguished into deciduous and coniferous forest, for the forest areas only the borders were used from the 2013 dataset, the areas were then filled by information from the Schiechtl/Stern forest vegetation map (https://www.data.gv.at/katalog/dataset/af193b31-303e-4dfb-b90d-347ee8e8accb).

This map of the current land use (raster data set with a resolution of 100 m x 100 m) was used for calibration and validation of the hydrological model. Due to limitations in the temporal resolution of the existing long-term climate data sets, the calibration and validation period had to be restricted to 2008 – 2015 and could not be extended to the 1970s as originally planned. The comparatively short period of time available for calibration and validation does not allow designing a transient land-use model experiment since the increment of time normally defined for updating the land cover, which usually covers a multi-year period of, e.g., 10 years, is small compared to the entire length of time series that are available for this task.

Data input for simulation (milestone 2.3)

For the simulation with the hydrological model, time series from the SnoMoS as well as from the Zentralanstalt für Meteorologie und Geodynamik (ZAMG) and the Hydrographic Service of Tyrol (HD) were analyzed and prepared. Some of the spatial input data for the catchments were available from previous projects (e.g. *SeRAC-CC*, 3rd ACRP call), others were prepared for the simulations in *STELLA*. Additionally we continued to maintain technical infrastructure for measurement of soil moisture and soil temperature, which was placed at eight representative sites in the Brixenbach valley in 2009 (see Fig. 4).

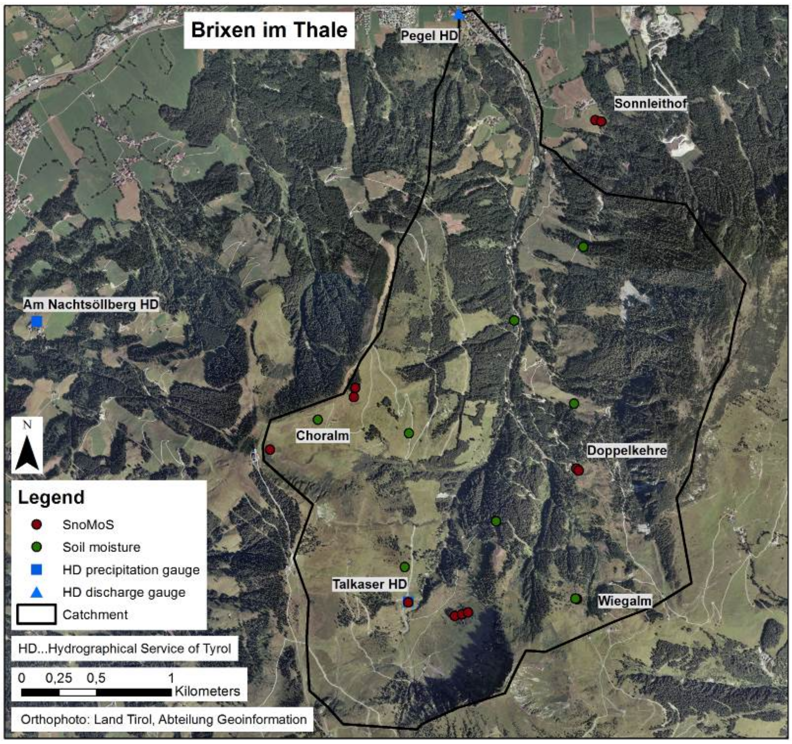

Fig. 4: Overview of soil moisture stations (since 2009) and the SnoMoS stations, installed for STELLA (2015 and 2016) in the Brixenbachtal.

Downscaled climate scenarios (milestone 2.4)

The new CMIP5-WRF scenario (Nadeem and Formayer, 2015), based on the emission scenario RCP 8.5 was bias corrected and downscaled by the partner BOKU MET. The newest available observational datasets – SPARTACUS (Hiebl et al., 2016) for temperature and EURO4M (Isotta et al., 2014) for precipitation – were used for bias correction. The CMIP5-WRF scenario can be interpreted as a possible worst case scenario for the Alpine region. In Fig. 5 the climate change signal for the CMIP5-WRF scenario and the three scenarios from *SeRAC-CC* for temperature and precipitation are shown. The temperature increase is in the order of 3 degrees until the end of the century, compared to the reference period 1981-2010 for the A1B based scenarios and up to 8 degree for the RCP 8.5 based model. On annual base, the A1B based scenarios indicate no significant signal for annual precipitation but the RCP 8.5 based scenario shows a decrease in the order of 20 percent.

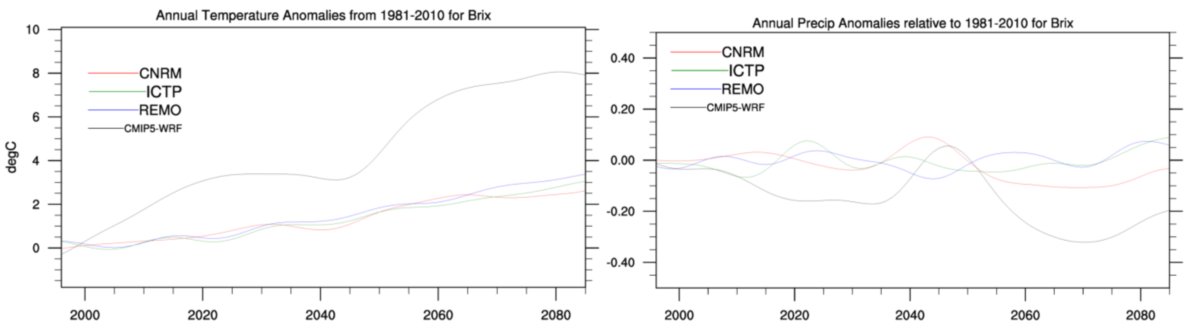

Fig 5: Climate change signal from the four used scenarios for the Brixenbach catchment for temperature (left) and for precipitation (right). The RCP 8.5 based scenario indicates a much stronger climate change signal than the A1B based scenarios.

The second project year was dedicated to the preparation of the meteorological input data (historical and climate change scenarios) for the hydrological model with 1 km² spatial and 1 hour temporal resolution. Main topic in data preparation was the temporal disaggregation of the bias corrected and localized climate scenarios from a resolution of one day to one hour. Temperature was disaggregated using daily minimum/maximum temperatures and three piecewise continuous cosine curves. For precipitation, stochastic functions were used with distributions derived from 10 minute precipitation statistics of recordings from stations in the vicinity of the target area (Koutsoyiannis 2003; Goler and Formayer 2012).

To jointly discuss the local climate change scenarios with the stakeholders, we put some emphases on preparing figures easily to understand. Hence, we used Walter/Lieth type climate diagrams (Walter, 1956) for the different time frames and climate models to visualize the climate and the climate change signal of the different scenarios. An example for the RCP 8.5 scenario is given in Fig. 6.

During the process of data preparation the consortium decided that only one model out of the three available model runs forced with A1B should be used for hydrological modelling, because the climate change signal of the three models are quite similar. Thus only the models CMIP5-WRF and CNRM- (ALADIN forced by the GCM ARPEGE) have been used for hydrological modelling.

Climate scenario data from the ÖKS 15 ensemble data set could not be used within this project, because the ÖKS 15 data set do not contain bias corrected and localized humidity and wind information, but these variable are needed for the hydrological modelling.

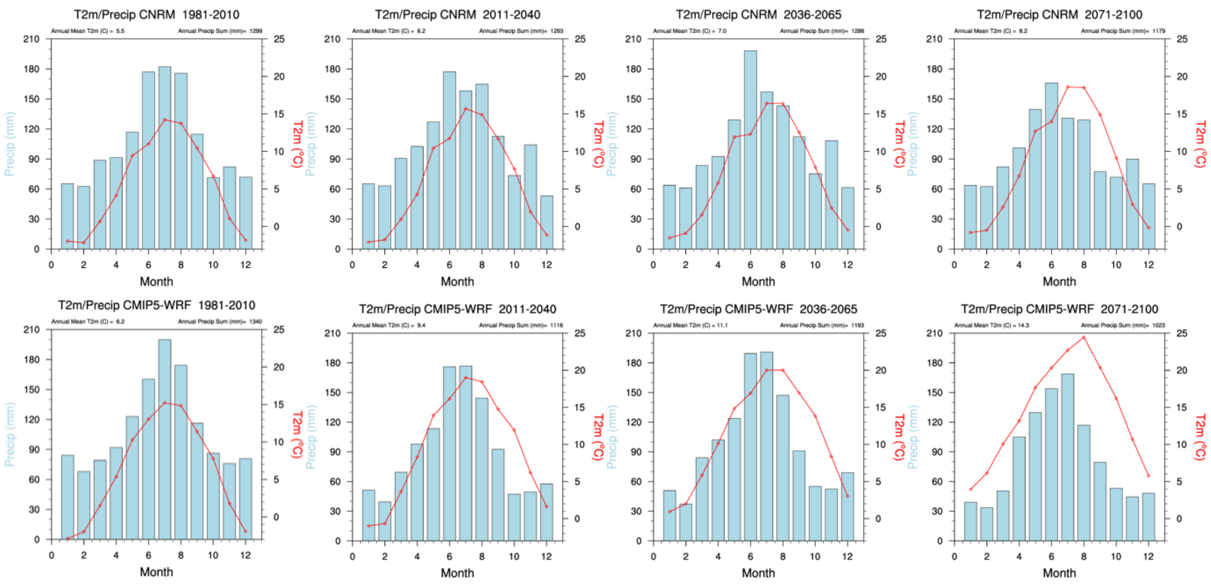

Fig 6: Walter/Lieth type climate diagrams for the Brixental for the reference period (left) and three time slices within the 21st century for the A1B rund (up) and the RCP 8.5 run (down).

WP 3: Development, calibration and validation of the modelling tool

The objective of this work package is to extend the hydrological model WaSiM (Schulla, 2015) with a snow-canopy interaction submodel for a better representation of inside-forest meteorological and snow hydrological conditions.

Modelling tool: Implementation of the canopy model in WaSiM-ETH (milestone 3.1)

The implementation of the snow/canopy interaction model was conducted in close cooperation with the developer of WaSiM (Schulla 2015), Jörg Schulla (Hydrology Software

Consulting, Zurich). The basic principles of the submodel are described in Liston and Elder (2006) and Strasser et al. (2011) (see Fig. 7).

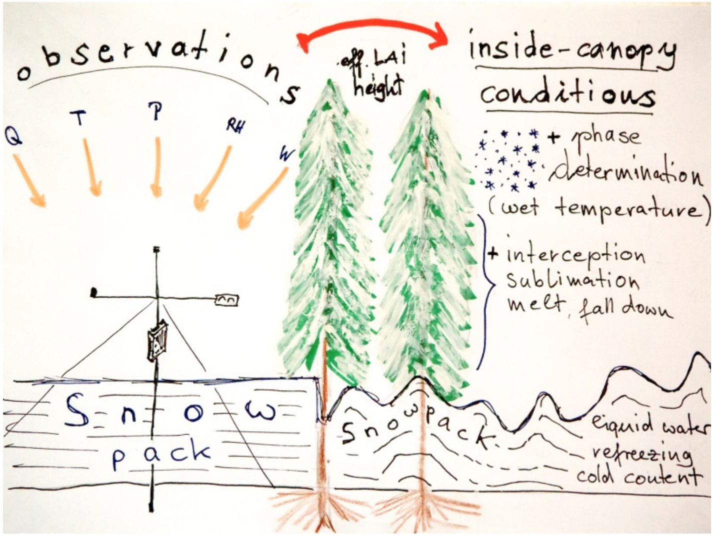

Fig. 7: Schematic diagram of the snow-canopy interaction model with the considered processes interception, melt and fall down, and sublimation of snow from the canopy. The model computes modified meteorological conditions beneath the trees for a separate energy balance computation of the snow surface in the forest.

A first prototype to be used with station data of single sites was set up, realized and published with the spreadsheet-based process model ESCIMO.spread v2 (Marke et al. 2016). In brief, the snow/canopy interaction model supplies modified meteorological conditions for beneath-canopy conditions. Subsequently it computes the interception storage and sublimation and melt processes from the trees, considering vegetation characteristics such as the leaf area index (LAI). These enhancements provide a mostly coherent picture of snow cover dynamics in forests. Fig. 8 illustrates the processes and interactions considered by the model. The new version of WaSiM was then calibrated and validated for the Brixental catchment using soil moisture and discharge data, and the recordings of the SnoMoS sensors and the wildlife cameras.

Model setup for the catchment (milestone 3.2), calibration/validation (milestone 3.3)

For the model setup in the Brixental the data prepared in WP2 was used. Since WaSiM is a complex, physically based hydrological modelling system, the procedure of calibration was chosen such that (i) the high computational needs of the model itself are accounted for, and (ii) the adjusting of the most sensitive parameters is an objective, repeatable process. Hence, the so-called lexicographical calibration approach has been set up which maps parameters to processes for optimisation using expert knowledge (Gelleszun et al., 2015).

For calibration, the modelled results were compared against runoff data, and observations collected with the SnoMoS low cost sensor network (Fig. 8). Thereby, the dynamics of snow-vegetation interaction could well be captured, both with respect to inside-canopy ground snow conditions, and interception of snow on the branches and leaves (Fig. 9). The simulated variability between forests and open sites also match the observed states very well. The Nash-Sutcliffe model efficiency is 0.63 for the calibration period (2008-2012) and 0.70 for the validation period (2013-2015).

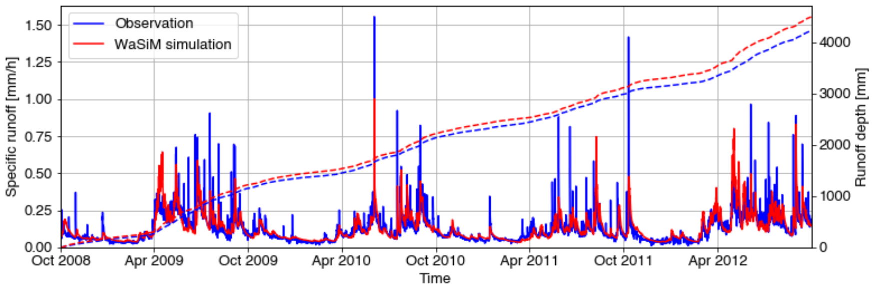

Fig. 8: Observed and modelled time series of specific runoff in the calibration period at Bruckhäusl gauging station. Dashed lines are cumulative values.

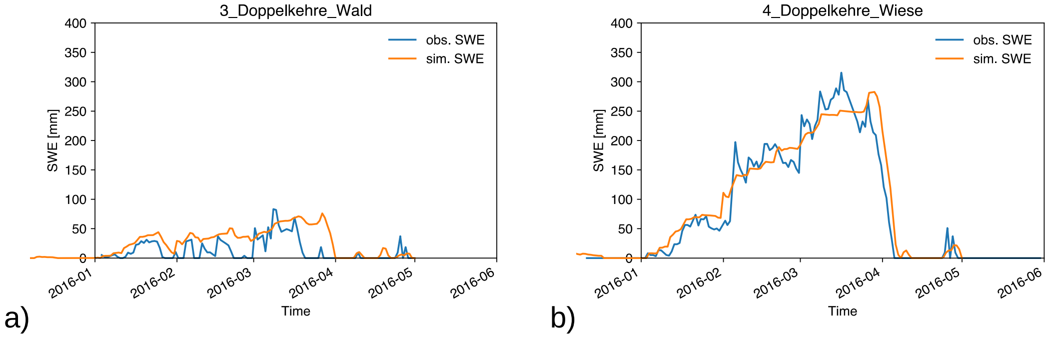

Fig. 9: Observed and modelled snow water equivalent for (a) coniferous forest and (b) open site conditions. Snow depth recordings from our photographic images have been transformed to SWE values with snow density measurements collected in the vicinity of the catchment by the Hydrographic Service of Tyrol.

Sensitivity analysis (milestone 3.4)

A sensitivity analysis was performed with the new WaSiM version by means of model runs with the canopy module switched on and off, respectively. Generally, the extended model, which was used for calibration, shows higher model skills. If the canopy model is switched off, the Nash-Sutcliffe model efficiency, RMSE (Root Mean Square Error), RSR (RMSE to Standard deviation Ratio) and correlation decrease (Table 1). On top of that, the canopy model reduces snowmelt peaks in the simulations which corresponds with the observations.

Table 1: Effect of switching off ("canopy model off") and on ("canopy model off") the new canopy model in streamflow simulation for the Brixenbach catchment (period 2009-2016).

Performance measure	canopy model off	canopy model on
Nash-Sutcliffe efficiency [-]	0.54	0.64
PBIAS [%]	3.15	3.22
RMSE [mm/h]	0.07	0.06
RSR [-]	0.68	0.60
Correlation [-]	0.77	0.81

WP 4: Socio-economic data acquisition

The objective of WP4 is to elicit knowledge on social-economic drivers of changes in forest management for different groups of forest owners.

Literature review (milestone 4.1)

At the beginning of the project we reviewed the existing scientific and non-scientific literature on adaptations of forest management practices to socio-economic and climate changes Scientific literature focussed on *The Austrian Assessment Report* (Kromp-Kolb et al., 2014) where Austria´s most relevant climate researchers contributed to this national offshoot of the IPCC-Report. The authors project an increase in the forest area due to afforestation of marginal agricultural land. In Austria about 31% of the total area are labeled as protection forests with a higher proportion in Tyrol, where 66% of forests are declared protection forests (Lexer et al., 2014). Forests have a good water retention capacity and therefore prevent and mitigate flood events (Maroschek and Lexer, 2010). Ecosystems with a long development period and habitats of the Alps above the tree line are particularly affected by climate change. Disturbances are strongly influenced by forest structure and composition. Increasing forest area in recent decades and silvicultural mistakes of past decades (e. g. the cultivation of spruce far outside of its natural range) have - together with climate change - intensified an Europe-wide disturbance regime (Lexer et al., 2014). Productivity of the forests will be enhanced, especially in mountain areas, and the growing season will be extended by climate change. However, abiotic disturbance factors such as storms, late and early frosts and wet snow events or wildfires could cause greater damage. Warm and dry years in connection with previous large-scale disturbances by storm and snow could significantly increase the share of economic calamity. Expected consequences include devaluation of assortments, falling timber prices by sudden oversupply in timber markets and higher planning and management costs. Warmer and increasingly dry climate, at least temporarily, increases stress for plants and causes a decrease in the resistance of the host tree populations to biotic damage factors. In this context, damage by bark beetles and thermophile insects is likely to increase (Lexer et al., 2014). According to Maierhofer (2009) more than 85% of managers of bigger forestry companies have already implemented adaptation measures to climate change, while small forest owners do less. Lindner et al. (2010) recommend adaption strategies on inventory level (tree species, thinning concepts and rejuvenation procedures), the level of forest administration (forest protection concepts, improved planning methods) and policy and governance (research efforts, training and promotion of logistics concepts for coping with calamities).

The review of non-scientific literature focussed on articles in Austrian agricultural-related magazines and monthly newspapers. In general it can be said that forest media took up climate change in their reporting. Global climate, annual report on climate or Biomass Conference are used as an opportunity to address climate change with regard to agriculture and forestry.

Analysis of expert interviews (milestone 4.2)

Based on the results of the literature review we conducted expert interviews between fall 2014 and beginning of 2015. After exploring the field and its basic categories (formation of knowledge and structural composition of forest owners) by initial key informant interviews, we developed a comprehensive guideline for further six expert interviews. The informants were selected according to functional criteria, to represent important stakeholder groups within the project area: rangers and foresters representing the public administration of forests, a timber merchant representing the economic interest group, a mayor incorporating communities as owners and stakeholders of woodlands and a forester of the Austrian Federal Forests (Österreichische Bundesforste, ÖBf) representing the semi-public sphere. The interviews were verbatim transcribed and coded for extensive analysis leading to.more than 150 theses on the function, management and changes of forests. These theses were instrumental for the construction of a quantitative survey and a first draft of storylines on the future development of the forest.

Generally, the results picture the forest as an active discoursive space, which incorporates lively flows of information, communication, extensive regulation and organization. Perspectives depend whether the stakeholder has economic, 'public' or mere professional interests in the forest. Human activity has significant influence on the development and well-being of the forest, which outbalances 'natural' parameters like climate change. Climate change itself in many cases is met with skepticism; if anything, it is welcomed as process dynamizing forest cultivation. Political or economic policies as well as short-term events (e. g. economic crises, monetary crises) are said to strongly shape the capabilities for sustainable management. Economic policies as well as short-term events (e.g. economic crises, monetary crises) strongly shape the capabilities for sustainable management. Consequently, forest owners management activities influence the forest structure. One highly relevant actor in the governance of forests is the timber industry. A (partially latent) inherent and chronic conflict between different stakeholders, especially between forest owners and public players (community representatives as well as leisure users) became apparent. An extensive discourse on being familiar with one´s forest as well as on the notion of 'identity' is discernible. In this context a notion of 'embeddedness' is highlighted against what is suspected as 'alienation' of 'anonymous' stakeholders from outside.

Property sturcture constitutes a factor with strong impact on forest cultivation. The larger the possessed area, the more economic outcome it provides to the owner, which in turn increases the incentive to manage the forest in a sustainabe manner. Especially in the Tyrol and in Austria in general structures of property are relatively stable and static.

Questionnaire to forest owners (milestone 4.3)

These qualitative data served as the basis for a quantitative questionnaire. The first idea was to send out a questionnaire to every forest owner in the project communities. As some communities are only partially in the catchment area of the Brixentaler Ache, we restricted the inquiry to communities which are entirely in the area (Hopfgarten, Itter, Westendorf and Brixen im Thale). We received the contact details from the administrative responsible forester. In total 902 forest owners were adressed. Due to cost reasons, we decided to collect answers from natural and legal persons via a web-based survey tool (Lime Survey). As a web server-based software, it enabled us to develop and publish the questionnaire online and collect responses centrally. This tool enabled us to design the questionnaire for natural and legal persons simultaneously. The forest owners were contacted via formal letter with a link to the corresponding questionnaire. Additional to that we 1) published short articles in newspapers of the municipalities with an invitation for the survey, 2) asked the forest rangers personally for advertising our project among the forest owners and 3) asked the regional chamber of agriculture to invite all forest owners with agricultural background via e-mail. Still participation was low and only 64 of the addressed 902 forest owners filled out the questionnaire completely.

Statistical analysis (milestone 4.4)

The statistical analysis was limited by the low response rate. 87,5% of the respondents were farmers. The size of the forest property of the respondents ranges from 0,4 to 38 ha (arithmetic mean 0,9 ha). 81,3% of the owners lived within 5 km of their forest property, only 4,5% resided in a distance of more than 20 km. Forest owners rated the protective function of forest against natural hazards as very important and appreciated the forest's function to be more important than its economic benefit. In conclusion, the results of the questionniare analysis underpinned the 150 theses, generated on the basis of the expert interviews.

WP 5: Joint generation of coupled climate and land use storylines

The objective of this work package is to elaborate the coupled storylines based on downscaled climate scenarios, stakeholder interviews and questionnaire results. The most realistic and most relevant storylines are selected in an interdisciplinary and participative process (stakeholder workshop).

Storylines (milestone 5.1), mid-term stakeholder workshop (milestone 5.2), matrix with realistic and relevant storylines (milestone 5.3)

For the storylines which were hydrologically modelled, in a first step climate and forest development / land use scenarios were defined. The climate scenarios are based on a moderate emission scenario (A1B) and a high emission scenario (RCP 8.5). The chosen representative for RCP 8.5 is a model run with high impact especially in the Alpine region and can be seen as a possible worst case.

The framework for elicitating the forest management / land use scenarios were based on Wilson's (2012) quality criteria for 'resilient' communities. Resilience means the capacity of a community (a system) to absorb shocks and the ability of reorganization in times of change. Therefore a community or region can be resilient or vulnerable. The resilience of a community is not just influenced by globalization processes, but is also based on different forms of environmental, economic and social capital of the local population within a community or region. Wilson (2012) evaluated global economic processes as basic parameters of a successful or failing region. Subsequently regional dominant forms of economic, social and environmental capitals contribute to a positive or negative development (Wilson 2010: 370). Starting from these basic considerations, the results of the quantitative and qualitative surveys were integrated and socio-economic scenarios were constructed.

For the development of the storylines (Fig. 10), the 150 sociological theses derived from the expert interviews were used to extract factors of influence regarding environmental, economic and social capital in the context of forests. The defined influencing factors on the resilience of the region were the initial position to tell the different storylines (Fig. 12). In total, storylines have been developed for two climate scenarios: A1B and RCP 8.5. For each climate scenario, a positive as well as a negative resilience scenario tells the future for a relocalized region (a), a glocal region (b) and a super-globalized region (c). Thus, in total 12 storylines for possible futures were developed (see Table 2).

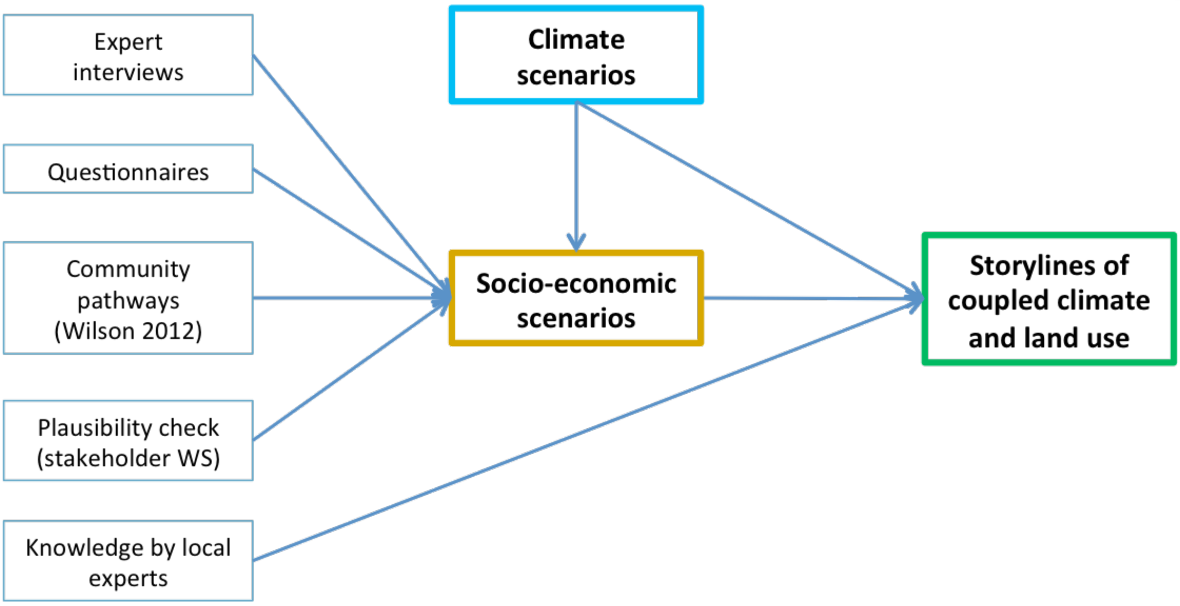

Fig. 10: Workflow for the development of storylines, integrating both climate and socio-economic scenarios.

At the first stakeholder workshop on 25th November 2015 in Kirchbichl the plausibility and consistency of the storylines was discussed with local stakeholder and experts. The influencing factors of each scenario were discussed with the participants regarding the impact on land-use and forest management. In order to facilitate the discussions, A1B was referred to as “Meran” and RCP8.5 as “Bologna” scenario, as these two Italian cities feature similar temperature conditions compared to the applied climate scenarios in 2050 in Brixental. Overall most of the storylines were considered plausible and consistent. Additional inputs of the participants were included and subsequently, starting from the effects on land use, condensed with the help of a local and a regional forestry expert info three general land use developments for the forest management:

- Ecological adaptation: The forest management consequently applies the political guidelines. The forest cover is dominated by an ecological, place-adapted mixed cultivation with a harmonious age structure. Thus, the forest is generally resilient towards natural hazards and simultaneously fulfils its different functions.
- Economical overexploitation and wildness: The increase in efficiency, cost reduction and short term results are in focus of the forest management. Nevertheless, legal regulations are respected and new, adapted species are reforested.
- Withdrawal and wildness: The forest cultivation in general is decreasing. With the withdrawal the forest becomes vulnerable against natural hazards.

Fig. 11 visualizes the classification of the storylines to forest/land use developments.

Table 2: Description of the 12 storylines

Relocalized region A relocalized region is based on regional small scale-value chains. Therefore, tourism, agriculture and forestry are focused on internal circular flows. Personal connections and traditional forms of economy are of importance.	**A1B**	In the **resilient** scenario the forest is mainly dominated by an ecological mixed cultivation with a harmonious age structure, and it fulfils its different functions. In a **vulnerable** scenario the forest is mainly dominated by a monoculture and the age structure of the trees is in disharmony.
	RCP 8.5	In a **resilient** scenario the forest is ecologically mixed and trees species are adapted to warmer temperatures. Thereupon it fulfils its different functions. In a **vulnerable** scenario the mixed cultivation is not enhanced and not adapted to warmer temperatures.
Glocal region A glocal region tempts to combine positive aspects of local and global development attributes. Therefore, local value chains are merged with the global marked.	**A1B**	In a **resilient** version of the scenario the forest is economically used, but even with partly monoculture, an ecological mixed cultivation dominates. In a **vulnerable** scenario the forest is dominated by a monoculture and its cultivation and economic function is abandoned.
	RCP 8.5	In a **resilient** scenario the forest is economically used and an ecologically mixed, adapted cultivation is dominant. The forest area extends towards higher altitudes. In a **vulnerable** scenario a monoculture in the forest is not adapted to the warmer and drier climate.
Super-globalized region A super-globalized region is economically completely focusing on the global commodity marked and forestry reacts on international demand.	**A1B**	In a **resilient** scenario the economic function of the forest is in focus, however ecological standards are fulfilled. Therefore, the cultivation is mixed and the age structure is in harmony. In a **vulnerable** scenario the forest is first overexploited and consequently abandoned.
	RCP 8.5	In a **resilient** scenario the warmer temperatures is seen as an engine of growth and the cultivation of species is adapted. Even if the economic use of the forest is dominating, it fulfils minimum standards of its other functions. In a **vulnerable** scenario forest is overexploited and a young monoculture is dominating the forest.

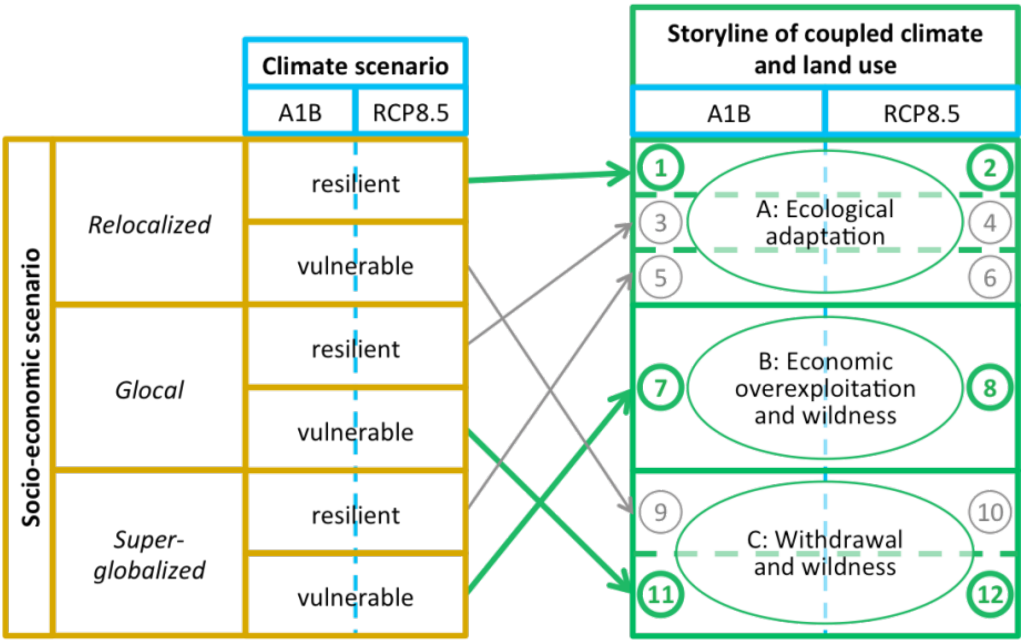

Fig. 11: Classification of the STELLA storylines to the forest/land use developments. The bold lines indicate the storylines chosen for hydrological modelling.

Transient land use maps of every storyline (milestone 5.4)

The storyline descriptions were translated into rules which allowed the production of transient land use maps, intensively supported by forest experts of the regional forest administration. Transient land use maps for every decade of every storyline (Fig. 12).

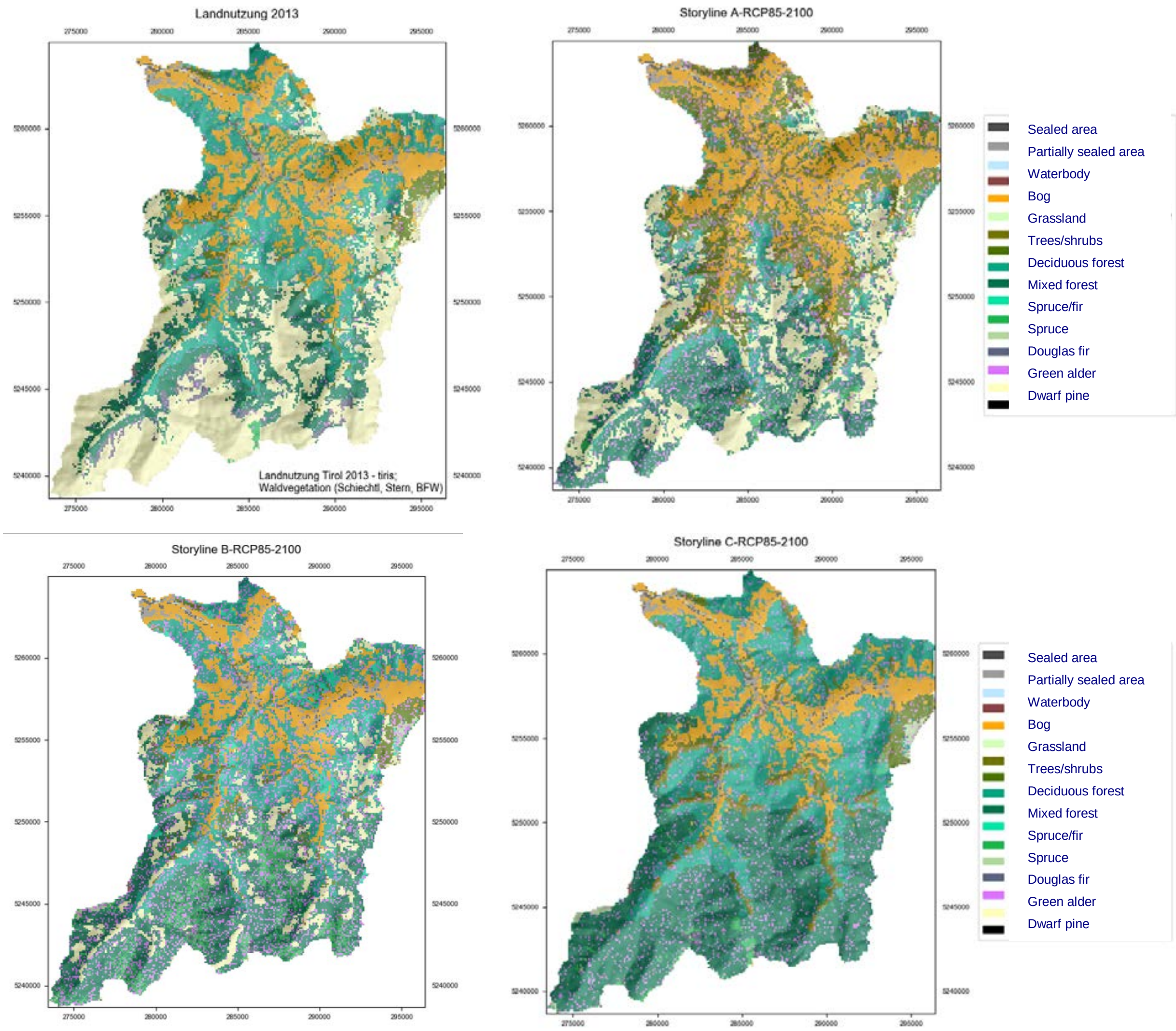

Fig. 12: Land use maps: current situation and situation 2100 for the storylines A-RCP8.5, B-RCP8.5, C-RCP8.5 (description of the storylines see table 2).

WP6: Hydrological Modelling of future storylines

In WP6, the transient hydrological modelling of the combined changing forest management and changing climate storylines are carried out, using the new extended version of WaSiM.

Streamflow / water cycle simulation of defined storylines (milestone M6)

For every storyline selected in WP5 the hydrological impact on the different sub-catchments is simulated. A methodology was developed that allows for transient modelling using the consecutive land-use maps for the re-initialization of WaSiM. This allowed for considering inherent thresholds, tipping points and non-linearities which influence the long-term behaviour of the hydrological system. Analyses focussed on streamflow, snow cover and evaporation. As forcing input for the hydrological model the control runs of the climate models are used.

Modelled runoff characteristics for 1981-2005 (gauge Bruckhäusl) correspond well with the observations (e.g., mean annual runoff, seasonality in terms of mean monthly specific runoff and mass curves) (Fig. 13 and 14). The good match of runoff characteristics highlights that (i) the bias correction for all meteorological quantities was applied successfully and (ii) the model setup which has previously been calibrated and validated is capable to reconstruct long-term runoff characteristics satisfactorily for the period from 1981 to 2005. Hence, the model is assumed to be capable of simulating future scenarios of runoff.

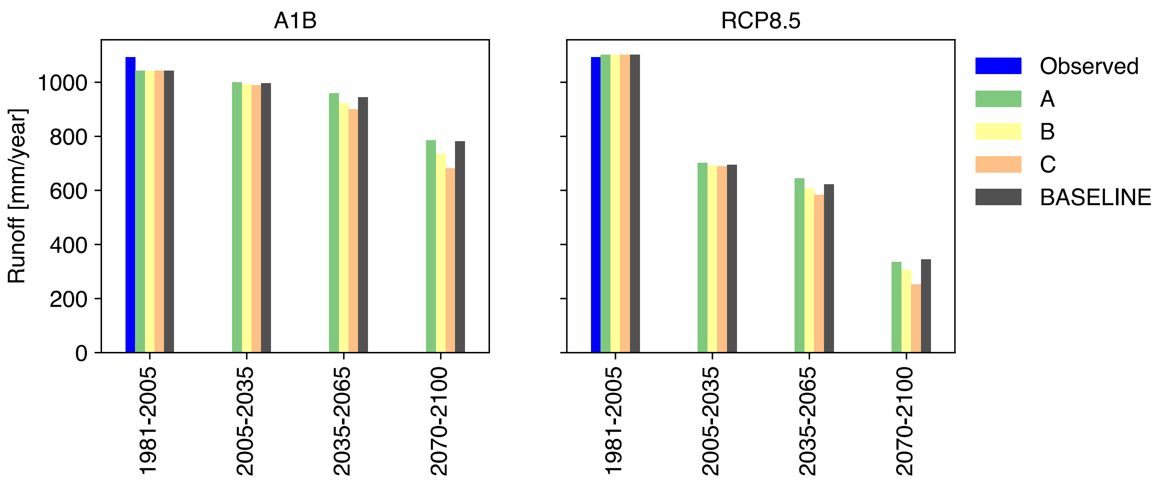

Fig. 13: Mean annual runoff computed for all storylines and different 30 years periods. The observed runoff refers to 1981 – 2005.

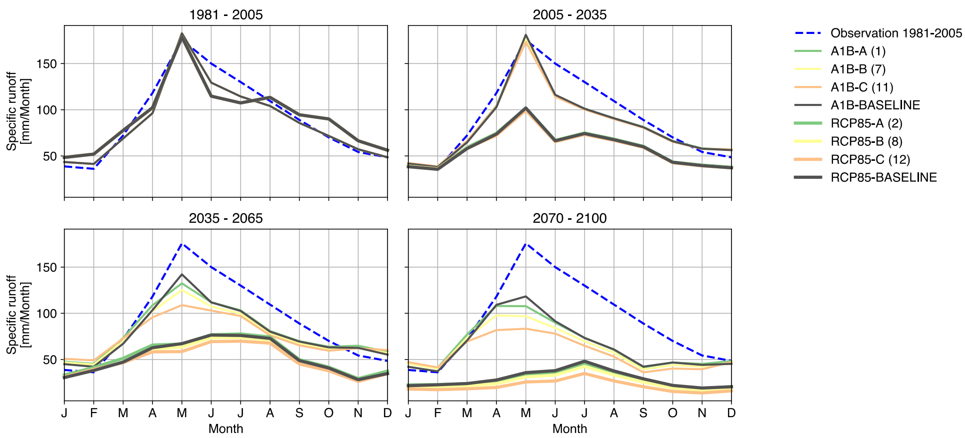

Fig. 14: Long-term averages of specific runoff computed for all storylines. The dashed blue line refers to the observed time series between 1981 and 2005.

In the future scenarios, runoff is expected to decline in all storylines. According to the simulations performed here, the decrease of runoff is already possible in the near future (2005-2035) in case of the normal RCP8.5 climate forcing. Thereby the differences between A1B and RCP8.5 runs are larger than the corresponding differences among storylines. However, these differences become larger over time showing largest differences at the end of the 21st century. In most cases, except for storyline C in the period of 2071-2100, a descending order of the storylines can be observed for runoff: A, BASELINE (land use as is), B, C (Fig. 16). Land use storyline affect water availability in the model (in terms of runoff as a surrogate). For instance, in the last decade of 21st century annual runoff in storyline C is 13% lower than for storyline A in case of A1B. Similarly, the same comparison reveals a difference of 25% if RCP 8.5 is considered.

Simulations suggest a low inter-annual variablity in the RCP 8.5 storylines. In contrast, if A1B is considered, the inter-annual variability is higher due to higher water availability. However, the different storylines reflect a different amplitude of Pardé coefficients (which represent monthly deviations from the annual mean) indicating that differences in land use prescribed by different storylines are largest during the spring maximum. In summer, autumn and winter, the differences are much smaller among different storylines which is in line with findings observed for the RCP 8.5 results. While the characteristics of a snowmelt dominated flow regime are still prevailing in the A1B storylines, a complete shift to a pluvial regime is obvious from the results of the RCP 8.5 runs. In the latter runs, by 2100 annual runoff amounts only to one third of the conditions found for the period 1981-2005. Similarly, annual runoff computed for the A1B storylines is about 30% below the reference.

The results suggest that the sustainable storyline (A) seems to be characterized by the highest water availability. The reasons for these complex interactions between climate and land use are manifold and require some additional discussion of the results achieved for other water balance components. We consider ETR (real or actual evapotranspiration) which is the rate of water that is 'lost' to the atmosphere. In contrast to the potential ET (ETP) it does not only account for meteorological conditions and plant specific characteristics which control the process of ET, but also takes water availablity into consideration (e.g., soil moisture). The definition applied here also incorporates snow sublimation from the canopy which is computed by the new snow interception model extension in WaSiM. ETR shows a complementary behaviour compared to runoff which is line with the water balance of a catchment: higher ETR results in lower runoff. Differences in climate forcing exceed differences in land use storylines (Fig. 15). The results show that ETR delivers a reversed ranking of the storylines. ETR increseases in ascending order: BASELINE, A, B, C (C is subject to highes ETR rates). Simulations suggest that ETR is 25% higher in the summer by the end of this century compared to current conditions if A1B is considered. In case of RCP 8.5, the increase in ETR amounts even to 50%.

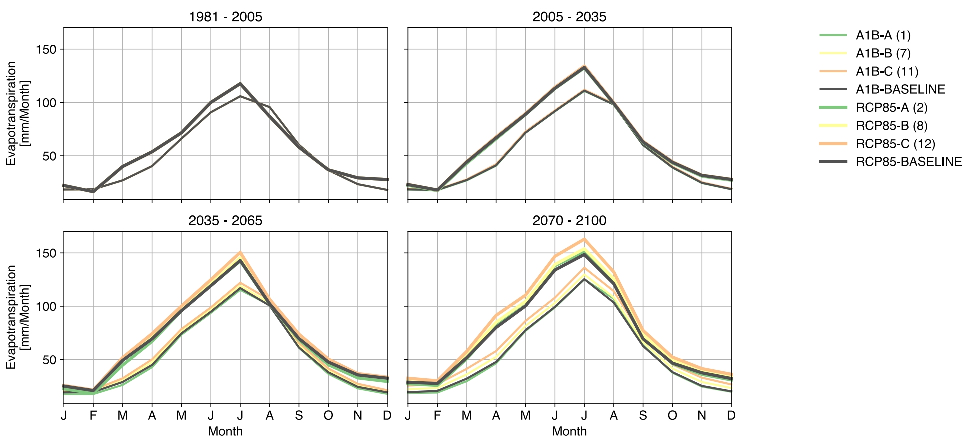

Fig. 15: Long-term averages of real (actual) evapotranspiration for the STELLA storylines.

Regarding snow the snow water equivalent (swe) on the ground is considered (without the snow intercepted in the canopy). As for the other water balance components climate forcing has the highest impact on swe variability (Fig. 16). For RCP 8.5, the seasonal snow pack only amounts to 10%-20% of the storage found in the present period. For A1B, swe decreases in the winter but is still an important water balance component in the future. By the end of the 21st century only 30% to 60% of past snow accumulation is computed by the model. The differences indicate a markable dependence on the storyline if the same climate forcing is considered. The descending order of swe in A1B is BASELINE, A, B, C.

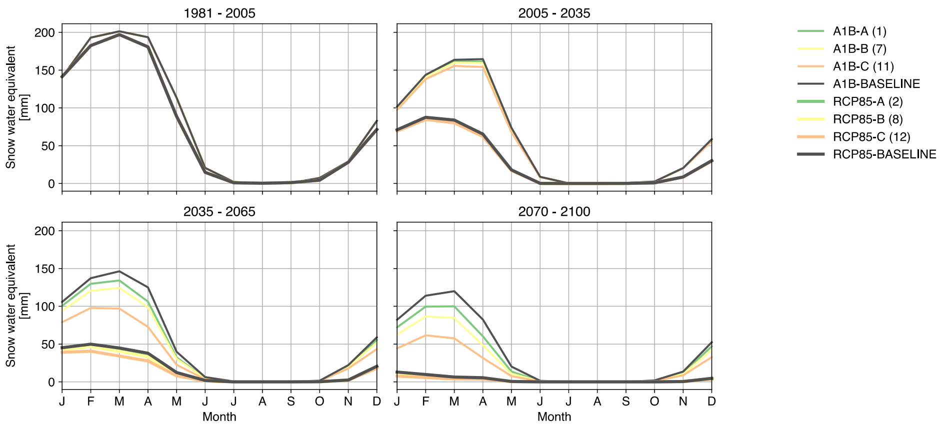

Fig. 16: Seasonal variability of snow in terms of long-term averages of monthly swe.

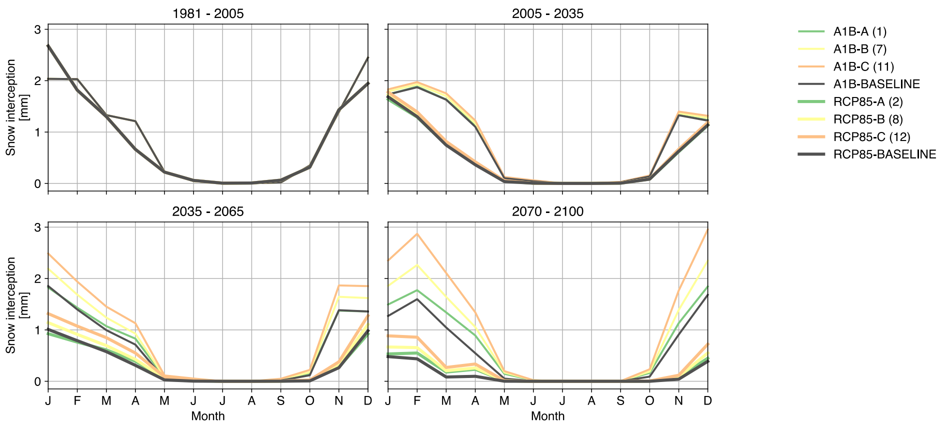

Fig. 17: Seasonal variability of snow interception in terms of long-term averages of monthly snow load on trees.

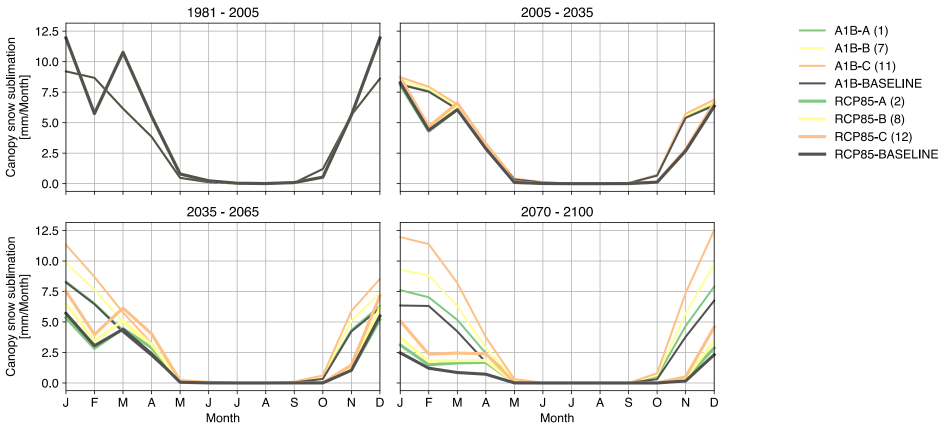

Fig. 18: Mean monthly sublimation rates computed for all storylines and different periods of time.

A spread of tall vegetation on the meadow areas increases atmospheric coupling and interception and, thus, sublimation (Fig. 17 and Fig. 18). The storylines B and C are hence subject to higher sublimation, further accentuating the summer water losses through evapotranspiration in a warmer climate. Sublimation losses of snow can duplicate (for the storyline C) in the climate scenarios, resulting in annual water losses of approximately 25 mm (A1B) and 10 mm (RCP8.5), respectively (Fig. 19).

WP7: Joint evaluation of results

WP7 aims at the evaluation of the project results, the translation of the hydrological impacts and the dissemination of the scientific findings to the scientific and non-scientific audience. The findings resulting from hydrological simulations were jointly evaluated by the project partners. For the scientific audience outcomes were communicated via conference talks (see chapter 4), scientific publications are in preparation (milestone 7.1). For the non-scientific audience an overview of possible hydrological effects and resulting consequences was presented in the second stakeholder workshop (30th May 2017, see also description of WP 1). A follow-up workshop for a broader audience will be prepared together with some of the stakeholders. The results were translated into comprehensive key statements (executive summary, milestone 7.3) and communicated to the press (see description of WP1).

5 Conclusions

In STELLA, results have been achieved on three different levels of scientific advance: (i) in the domain of social sciences, we have developed plausible and consistent storylines of potential future land use development, harmonized with scenarios of future climate, for the Brixental in a transdisciplinary stakeholder process; (ii) in the domain of natural sciences, we have further extended the physically based hydrological catchment model WaSiM with a snow-canopy interception module to consider the temporal storage of snow inside a forest and quantify the processes of interception and sublimation as well as to better simulate the modified evolution of the seasonal snowpack on the forest ground; (iii) as integrative synthesis, we have combined the jointly developed storylines with scenarios of future climate according to the A1B and RCP 8.5 emission pathways and simulated their combined effects on the components of the catchment water balance.

The results can be summarized as follows:

- The socio-economic scenarios were constructed as response to the globalization process and the environmental, economic and social capital of the local population, i.e. a resilient or vulnerable pathway along which a community develops into the future. The resulting relocalised, glocal or super-globalized community development was then integrated with the resilient or vulnerable criterion and finally condensed into three different land use developments for the forest management: ecological adaptation (resilient), economical overexploitation and wildness, and withdrawal and wildness (the latter two both vulnerable). These three general development paths are to be combined with the A1B or RCP 8.5 emission pathways. The resulting six STELLA storylines were used to derive respective transient time series of land use evolution from the present to the future as input for the hydrological modelling. As a general picture, in the storylines B and C the fraction of forested areas grows from decade to decade, mainly in steeper S-facing slopes and previously cultivated mountain farm land. In C this process starts earlier (abandonment).

- To consistently simulate the effects of a changing forest management on the water balance terms in the Brixental catchments, the physically-based hydrological model WaSiM was extended with a snow-canopy interception and sublimation module. For proper parameterization and validation purposes, a set of SnoMoS sensors to monitor the meteorological variables inside the canopy – and outside, for comparison – was installed, as well as automatic cameras. Their data was used to properly parameterize and validate the snow/canopy module. The purpose of this new module is twofold: one, the ground snow cover inside the forest is simulated with modified meteorological variables, and the snow intercepted on branches and the stem is divided into fractions sublimating, melting or falling down. With the new WaSiM version, the water balance simulation in a forest canopy now also includes the sublimation losses of previously intercepted snow, and streamflow simulation is improved. Validation of the new WaSiM version provided a Nash-Sutcliffe efficiency of 0.7.
- In six modelling experiments, we have simulated the water balance of the Brixental catchment for the three storylines ecological adaptation (A), economical overexploitation

and wildness (B), and withdrawal and wildness (C), each combined with both A1B and RCP8.5 future climatic conditions, until 2100. Projected temperature increase until then for A1B is 3 degrees, for RCP 8.5 it is 8 degrees. Respective precipitation change only occurs in the RCP 8.5 future, and is a decrease in the order of 20%. Runoff amount for the A1B future (2070-2100) is 30% below the reference (1981-2005), for RCP 8.5 only one third of streamflow amount remains. Main reason for the extraction of water from the water balance is the increasing evapotranspiration of 25% (A1B) and 50% (RCP8.5). The growing forest in storyline C leads to a decrease in annual runoff of 13% (A1B) and 25% (RCP8.5), respectively. Reduction of the snow cover is more than 50% in A1B, and 90% in RCP8.5. Water losses by snow sublimation are comparatively small, but enhance the reduced input to streamflow runoff in the future climate scenarios, mainly for the storylines with growing forests.

C) Project details

6 Methodology

In *STELLA*, a truly inter– and transdisciplinary methodology has been developed and applied to scientifically go beyond the common climate change impact approach in hydrological modelling. Local actors and specialists from forest management and planning in the Alpine Brixental have been involved from the beginning of the project to jointly construct storylines of potential future development of their communities and land with respect to agriculture, farming and mountain farm cultivation. These storylines follow the criteria of plausibility and consistence with the socio-economic and climatic framing conditions. The latter are given by the two common emission paths A1B and RCP 8.5, and as such expand the range of potential warming that can be expected for the future.

This inter- and transdisciplinary methodology is a toolset that can be adapted to other regions and socio-economic settings. *STELLA* is a successful feasibility study that has proven that combined co-evolution of land management and climate in a joint, meaningful storyline is a meaningful way to force a physically based hydrological model. We have made an important step further than the classical one-factor-only type of impact.

Results show that the wilderness in forest management that can potentially be the consequence of certain types of storylines can lead to additional loss of water in the system, i.e. a positive feedback to the expected drying in a warming climate. This knowledge of the response of the system can be used as important basis for developing strategies to adapt to and mitigate potential negative effects of climate change in the Alpine water balance.

Fig. 19 shows the chosen workflow for STELLA. For a detailed description of the chosen methods and the work packages see chapter 4.

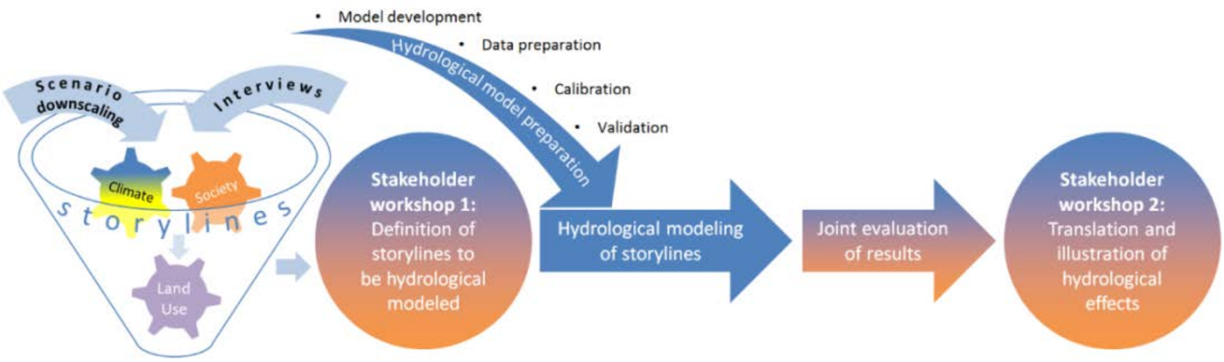

Fig. 19: Workflow of the research project STELLA.

7 Work- and time schedule

Fig. 20 shows the work plan and time schedule of the project.

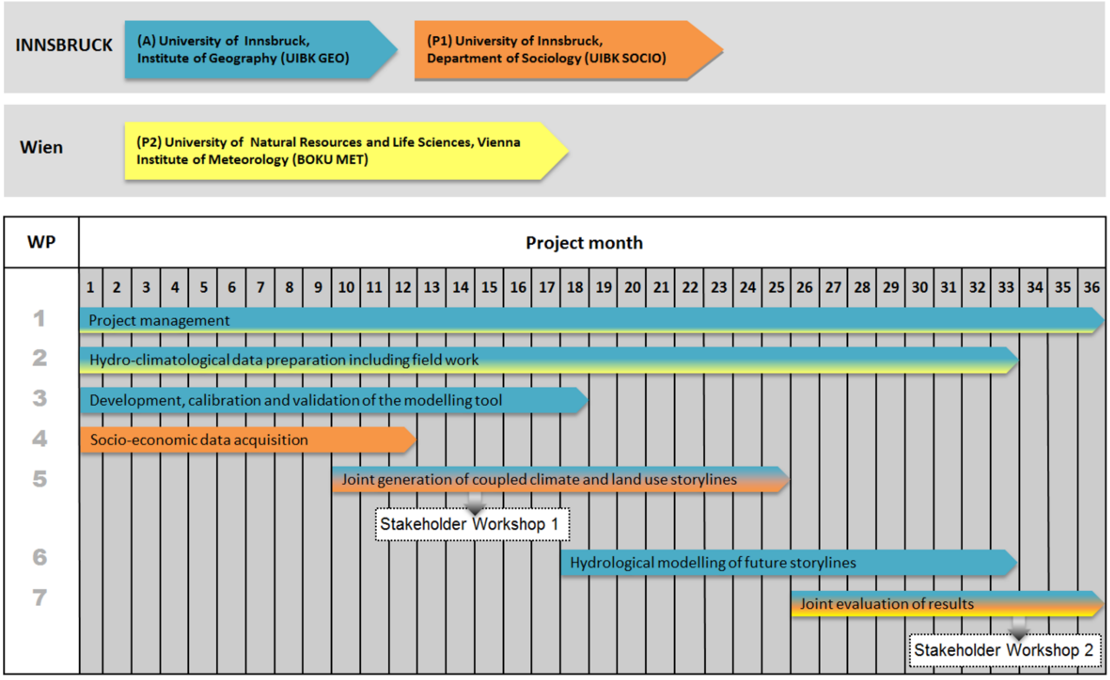

Fig. 20: work plan of the project STELLA.

8 Publications und Dissemination activities

Project workshops

- Kick off meeting (13 August 2014)
- Project meeting (28 September 2015) of all project partners in order to plan the ongoing second project year and to prepare the stakeholder workshop.
- Stakeholder workshop (25 November 2015): Description see chapter 2.2 (WP 1, WP 5)
- Project meetings of UIBK GEO and UIBK SOCIO order to discuss the results and implications of the stakeholder workshop on 26 January 2016 and 17 May 2016.
- Project meetings of UIBK GEO and UIBK SOCIO with forest experts of the regional forest administration to discuss the future forest management (4 April 2016).
- Project workshop (2 March 2017) of all project partners in order to plan the project finalization and the second stakeholder workshop.
- Stakeholder workshop (30 May 2017): Description see chapter 2.2 (WP 1, WP 7).

Publications

Papers:

Marke, T., Mair, E., Förster, K., Hanzer, F., Garvelmann, J., Pohl, S., Warscher, M. and Strasser, U. (2016): ESCIMO.spread (v2): parameterization of a spreadsheet-based energy balance snow model for inside-canopy conditions, Geosci. Model Dev., 9, 633-646, doi: 10.5194/gmd-9-633-2016.

Strasser et al. (2018): Storylines of combined land use and climatic drivers and their hydrological impacts in an alpine catchment (Brixental/Austria). In preparation for Water Resources Research.

Schermer et al. (2018): The role of alpine pastures for adaptations to climate change. In preparation for Agronomy, special issue "Climate Change in Agriculture: Impacts and adaptations", Einreichdatum: 31.5.2018.

Stotten, R. and Schermer, M. (2018): Participatory socio-economic scenarios for land use change. Paper in preparation for the 13th European IFSA Symposium (International Farming Systems Assciation). Farming systems: facing uncertainties and enhancing opportunities, 01 – 05 July 2018, Chania, Crete, Greece.

Förster, K., Garvelmann, J., Meißl, G. and Strasser, U. (2017): Modelling of snow-canopy interactions for mesoscale hydrological applications using WaSiM. In preparation.

Poster presentations:

Mair, E., Marke, T., Meißl, G., Pohl, S. and Strasser, U. (2014): Innovative low-cost Sensortechnologie für das Monitoring von hydroklimatologischen Waldbestandsprozessen zur Validierung der Wasserbilanzmodellierung in alpinen Einzugsgebieten. Poster presentation at the Tri-nationaler Workshop „Hydrologische Prozesse im Hochgebirge im Wandel der Zeit" hosted by the Hydrological Societies of Germany, Austria and Switzerland in Obergurgl (29.09.2014-01.10.2014).

Mair, E., Marke, T., Meißl, G., Pohl, S. and Strasser, U. (2015): Hydroklimatologische Modellierung der Schnee-Wald-Interaktion für das alpine Einzugsgebiet des Brixenbachs. Poster presentation at the 16. Österreichischer Klimatag in Vienna (28.-30.04.2015): 134-135.

Strasser, U., Formayer, H., Förster, K., Marke, T., Meißl, G., Schermer, M., Stotten, F. and Themessl, M. (2016): Storylines gekoppelter Entwicklung von Klima und Landnutzung und ihre hydrologischen Auswirkungen in alpinen Einzugsgebieten – das Beispiel des Projektes STELLA (ACRP, 6th call, 2014). Poster at 17. Klimatag, 6.-8. April 2016, Graz: 168-169.

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Förster, K., Meißl, G., Marke, M., Pohl, S., Garvelmann, J., Schulla, J. and Strasser, U. (2017): A snow-vegetation interaction extension for the Water Balance Simulation Model (WaSiM). Geophysical Research Abstracts Vol. 19, EGU2017-2620. http://meetingorganizer.copernicus.org/EGU2016/EGU2016-15126.pdf.

Förster, K., Formayer, H., Marke, T., Meißl, G., Schermer, M., Siegmann, M., Stotten, R., Themeßl, M. and Strasser, U.: Interdisziplinäre Entwicklung gekoppelter Storylines von Klima und Landnutzung und ihre hydrologischen Auswirkungen in alpinen Einzugsgebieten. Tag der Hydrologie 2017, Trier, 23.03.2017: 23. https://www.uni-trier.de/fileadmin/fb6/prof/PHY/PDF-Dateien/TdH2017_4Abstracts_Poster.pdf.

Oral Presentations:

Marke T., Garvelmann, J., Mair, E., Hanzer, F., Förster, K., Pohl, S. and Strasser, U. (2015): ESCIMO.spread v2: Parameterization of a spreadsheet-based snow model for inside-canopy conditions. Oral presentation at the EGU General Assembly 2015 in Vienna (12.-17.04.2015).

Strasser, U., Formayer, H., Förster, K., Marke, T., Meißl, G., Schermer, M., Stotten, F. and Themeßl, M. (2016): Storylines of socio-economic and climatic drivers for land use and their hydrological impacts in alpine catchments - the STELLA project example. Oral presentation at the EGU General Assembly 2016 in Vienna (18.-22.04.2016). http://meetingorganizer.copernicus.org/EGU2016/EGU2016-2288-1.pdf.

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Förster, K., Meißl, G., Marke, T., Pohl, S., Garvelmann, J., Schulla, J. and Strasser, U. (2017): A canopy snow interception extension for WaSiM. 3rd WaSiM user conference, 18.-19.10.2017, Leibniz-Rechenzentrum der Bayerischen Akademie der Wissenschaften, Garching. http://www.wasim.ch/de/dialog/events.htm.

Garvelmann, J., Pohl, S., Förster, K., Warscher, M., Strasser, U. and Kunstmann, H. (2017): Monitoring und Modellierung von Mikrometeorologie und Schneedeckenvariabilität in bewaldeten, subalpinen Untersuchungsgebieten im Schwarzwald und den nördlichen

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Förster, K., Formayer, H., Marke, T., Meißl, G., Schermer, M., Siegmann, M. Stotten, R. and Strasser, U. (2017): Storylines von Klima- und Landnutzungsänderung und deren Einfluss auf den Wasserhaushalt im Gebirge – Eine Synthese aus Messkampagnen, Stakeholderworkshops und Modellierungen, Abstracts, Tag der Hydrologie, 22./23. März 2018, Dresden.

Stotten, R. and Schermer, M. (2018): Participatory socio-economic scenarios for land use change. 13th European IFSA Symposium (International Farming Systems Assciation). Farming systems: facing uncertainties and enhancing opportunities, 01 – 05 July 2018, Chania, Crete, Greece.

The project and its aims were presented at the "Forsttagsatzung" in Hopfgarten in Brixental, where all forest owners meet once a year (2.3.2015). The results of the project were also presented to farmers at the Tiroler Almwirtschaftstag (19.10.2017) by Ulrich Strasser and Markus Schermer.

Announcements of the quantitative survey and a short project description in regional newspapers with the title "Wald, Quo Vadis?": Westendorfer Bote (Westendorf, Juni 2015), p. 18, Hopfgartner Blattl (Hopfgarten, Juli 2015), p. 9, Brixner Zeitung (Brixen im Thale, Juli 2015), p. 16, Gemeindeblatt Itter (Itter, Juni 2015), p. 9.

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

Die Fördernehmerin / der Fördernehmer erklärt mit Übermittlung der Projektbeschreibung ausdrücklich über die Rechte am bereitgestellten Bildmaterial frei zu verfügen und dem Klima- und Energiefonds das unentgeltliche, nicht exklusive, zeitlich und örtlich unbeschränkte sowie unwiderrufliche Recht einräumen zu können, das Bildmaterial auf jede bekannte und zukünftig bekanntwerdende Verwertungsart zu nutzen. Für den Fall einer Inanspruchnahme des Klima- und Energiefonds durch Dritte, die die Rechtinhaberschaft am Bildmaterial behaupten, verpflichtet sich die Fördernehmerin / der Fördernehmer den Klima- und Energiefonds vollumfänglich schad- und klaglos zu halten.