Science Plan

on the strategic development of climate research in Austria

November 2018

Table of contents

Preamble

The process of developing a Science Plan dates back to the beginnings of the Climate Change Centre Austria (CCCA). It was initiated in November 2011 by the launch of a project of the former Federal Ministry of Science and Research and by the establishment of a CCCA working group. Since then, the development of the Science Plan has been on the agenda of the annual CCCA General Assemblies, where the respective developments have been presented, documented, and discussed with the CCCA member representatives.

A detailed history of the Science Plan is available on the CCCA website (www.ccca.ac.at).

So as to render the development of the Science Plan as participative and transparent as possible, all formative stages offered various opportunities for participation: from February 2012 to May 2013, Austrian climate researchers were able to partake (for instance via workshops) in the process which defined common goals, research areas, and steps.

In April and May 2016, a public comment process was conducted to allow the widest possible involvement of interested individuals. The CCCA community was kept up to date on the development of the Science Plan via the CCCA newsletter on regular basis. The Science Plan was, moreover, coordinated with the Austrian Assessment Report (APCC AAR14), which resulted in the identification of current research topics.

For quality assurance, review editors provided support during the drafting process of the present version of the Science Plan (as of March 2017) in its final stage. This present version was submitted and approved in accordance with the CCCA Statutes (§10) in March 2016 during the 9th CCCA General Assembly.

I. Introduction

The Science Plan originated in November 2011, when the former Federal Ministry of Science and Research (now Federal Ministry of Science, Research and Economy) tasked the Climate Change Centre Austria (CCCA) with developing a Science Plan for Austrian Climate Research. The CCCA's key responsibilities are: to provide continual, long-term co-operation and networking opportunities among its members; to facilitate access to all relevant data on climate change; to further the exchange of climate change-related models, tools, and research approaches; to improve the quality and efficiency of climate research in Austria; to conduct lobbying activities on political and strategic levels; to establish networks and coordinate research.

In keeping with the CCCA's self-conception, the Science Plan is designed to foster climate research in Austria. Interlinking globally relevant research questions and national research requirements will improve the quality of Austrian climate research and increase its visibility. The Science Plan aims to engender maximum efficiency by drawing on current developments and promoting national synergies and core competencies. Highlighting certain Science Plan topics is in keeping with the CCCA's mission to support both the public and policy makers in addressing climate change challenges by providing scientifically sound findings.

The Science Plan identifies relevant research topics based on gaps in scientific knowledge, established research competencies, as well as societal knowledge requirements and needs for action. These topics were determined by the Austrian climate research community in an open process and are modelled on international programmes. Climate change poses one of the biggest current and future challenges which affect all areas of the natural environment as well as society. As a result of the manifold complex connections between humans and the environment, understanding the causes and drivers of climate change is an essential prerequisite for developing strategies to cope with climate change and its impacts. Climate research encompasses the scientific analysis of climate change and its physical, political, economic, cultural, and societal causes as well as the assessment of socio-economic and environmental climate impacts.
The aim is to provide information on potential climate change mitigation strategies and measures, adaptation to climate change, and on transformation towards a climate-friendly society, which is a requirement for the successful implementation of sustainable measures.Mitigation, adaptation, and transformation overlap in many ways. In the context of climate change, they are, moreover, linked to changes in societal patterns of production, consumption, and behaviour, and to how political measures are drafted, institutionally defined, and implemented (policy and governance).

I.I. Science Plan Objectives

The Science Plan presented by the CCCA is intended to provide orientation for both the research community and research policy makers and should be an incentive to develop an advantageous course for Austrian climate and climate impact research over the next five to seven years. The CCCA Science Plan thus represents a strategic document which

- serves as the mission statement and basis for co-ordinating Austrian climate research;
- contributes to increasing the societal efficacy and acceptance of climate change research beyond the parameters of scientific excellence, so as to fulfil society's broad need for information;

- supports the decisions-making processes concerning the direction of Austrian climate research according to societal and/or scientific priorities;
- promotes Austrian climate research so as to foster networking activities with the international scientific community and thus increases the visibility of Austrian climate research in order to create synergies and avoid parallel activities;
- contributes to important international developments such as the process of defining and implementing the United Nations' Sustainable Development Goals (SDGs) or the activities of the Intergovernmental Panel on Climate Change (IPCC) which formed the basis for the 2015 COP21 Paris Agreement – a historic milestone in climate change mitigation and adaptation;
- functions as the basis for providing research results which can be utilised in the form of climate services.

The Science Plan's guiding principle is to expand scientific knowledge by conducting scientifically and societally relevant research on climate topics in both an Austrian and a global context. The focus on Austrian realities and needs also involves an affiliation to the international research community. Embedded in disciplinary, interdisciplinary, and transdisciplinary contexts, both basic and applied research contribute to knowledge gain.

1.2 Structure of the Science Plan

Although the Science Plan is conceived as a five- to seven-year research strategy (comparable to the publication periods of IPCC reports), it should be considered a living document which can be scrutinised and adapted whenever necessary. The Science Plan pinpoints existing requirements and gaps in scientific knowledge, thus identifying future research needs. It is also meant to help create an appropriate framework for national research funding policies.The Science Plan adheres to a structure which follows the International Assessment Reports (IPCC) and the APCC Austrian Assessment Report (AAR 14).

The research needs for individual research topics are therefore presented according to the following five subareas: Influencing Factors and Characteristics of Climate Change (chap. 3.1), Climate Change Impacts (chap. 3.2), Adaptation to Climate Change (chap. 3.3), Mitigation of Climate Change (chap. 3.4), and Societal Transformation Processes (chap. 3.5). This structure is supplemented by a chapter on cross-sectional interdisciplinary and transdisciplinary topics (chap. 3.6). These may either be methodologically relevant for all five subsections or address issues particularly relevant to the Austrian context to which all subsections can contribute.

The final chapters are dedicated to establishing a general framework necessary for high-quality climate research (chap. 4) and to presenting the status quo of climate research in Austria and current competencies (chap. 5).

Fig. 1

2. New Challenges for Science

2.1 The (Self-)Conception of Science

Global change in general and climate change in particular pose major scientific challenges. They go beyond the question of how to solve or overcome specific problems and impact on how science understands and defines its own role. The use of fossil energy resources and the steady increase in technological developments since the beginning of the Industrial Revolution have made the inherent nexus between society and the natural environment palpable.

In order to tackle the subsequent challenges, research of individual science disciplines must be complemented by applying inter- and transdisciplinary approaches.Numerous scientific aspects of climate change and its impacts remain unresolved. Still, a plethora of related questions in the social sciences – whether sociology, economics, law, or psychology – remain unanswered.

Finally, also contributions from the humanities – such as from philosophy or history – are certainly relevant. Furthermore, inter- and transdisciplinary co-operation is necessary when it comes to addressing the increasing complexity of problems not confined to a specific discipline. However, academic disciplines concerned with climate change are currently facing far more extensive challenges. The task at hand is no longer merely to develop interdisciplinary solutions in the context of both the generation of system knowledge through basic research or in utilising this knowledge in applied research. The increasingly important task is, rather, to generate transformation knowledge.

Against this backdrop, scientists are facing challenges in the philosophy of science in terms of ethical, psychological, sociological, and linguistic issues:

A transdisciplinary dialogue between science, the public, and decision-makers is necessary so as to ensure that society takes notice of and considers solutions proposed on the basis of scientific research for the achievement of sustainability goals. If science and society join forces in generating knowledge and defining relevant common issues, this will create a sense of ownership which is, in turn, necessary to trigger a social transformation process that goes far beyond reactive adaptation and prevention. In inter- and transdisciplinary contexts, scientific progress cannot only to be measured against established mono-disciplinary criteria, but also in terms of the added value it contributes to solving societal problems (societal impact).

Research on global climate change and the corresponding societal changes is post-normal and raises many ethical questions: What role do scientists play in public discourse? Where do scientists' responsibilities lie when policy makers and the public expect information and solutions which are often the subject of basic research?

The question is whether the sciences concerned with climate change have the appropriate tools and methods for conducting respective research. Both the role of scientists and scientific institutions, the inherent laws of the scientific system, and how the public perceives of them are, likewise, essential.
In this context, two-way communication is necessary to ensure that the information provided is credible, relevant, and legitimate.
Stakeholders should therefore be involved in the research process from an early stage onward (co-design, co-production, co-exploration).

2.2 Science Communication

Given the immense relevance of climate research for society, communication between science and the public is crucial. The uncertainties inherent in climate-relevant data (which may serve as a basis for decision making) and the question of how to communicate these uncertainties pose major problems when informing decision-makers and the wider public. Regardless of the scientific fields involved, the way in which climate data is processed is an important means of making the respective content comprehensible according to its context. Climate research is therefore called upon to pay close attention not only to new research results but also to their communication.

The information and messages should be understandable and should not suggest invalid conclusions. In the areas of citizen science / responsible science appropriate approaches do already exist. It would be beneficial to reach a balance between scientific excellence and the ability to make scientific findings accessible to a wider audience.

Special attention should also be paid to social dynamics, which, as underlying structures, significantly influence the channels of communication when scientific knowledge is communicated.

3. Research Priorities

In terms of its structure, the current chapter follows the IPCC publications and the APCC AAR14. Chapter 3.1 discusses research questions concerning the physical biogeochemical climate system, while chapter 3.2 examines climate change impacts. Chapter 3.3 is dedicated to climate change adaptation, chapter 3.4 to mitigation strategies, and chapter 3.5 to developing transformation processes that lead paths towards a sustainable society. The final chapter, chapter 3.6, discusses inter- and transdisciplinary aspects of selected cross-sectional topics.

Research results constitute the scientific basis for climate services offered. In order to provide reliable information, research must address both interdisciplinary questions and questions pertaining to traditional scientific disciplines. This requires applied as well as excellent basic research.

Climate change is a global problem with regional impacts. The topics of the following sections were therefore chosen from two perspectives: Which significant contributions can, and should, Austria provide to advance the understanding of climate change, its causes, and its prevention? What research is essential to understand and project climate change impacts in Austria.

Thematically, the Science Plan also follows international research activities and programmes such as Future Earth or the World Climate Research Program (WCRP).

On account of the diverse topics, fields, and disciplines represented in the Science Plan, numerous international points of contact, programmes, and activities have been consulted during the preparation of this document.Austria's participation in these activities and programmes is important to ensure the high quality of Austrian climate research and to provide incentives for international climate research.

3.1 Research Area I: Climate Change, Drivers And Characteristics

Research Area I mainly covers topics addressed in both the IPCC AR5 of WG1 and the first volume of the APCC AAR14, giving high priority to intersections with topics of other volumes of the corresponding reports. However, there is no claim to completeness, especially regarding globally relevant questions, since making such large-scale statements is neither feasible nor desirable for a country the size of Austria.

The research goal in this area is to gain a better understanding of the climate system and its predictability. The direct benefit of such research is to provide robust information for climate change mitigation and adaptation strategies. Research Area I covers the topics of improving process understanding, collecting and analysing observation data, modelling the climate system, and developing approaches at the intersection with climate impact research.

3.1.1 Climate Processes and Climate Process Understanding

The Austrian climate is generally determined by large-scale and global aspects: by the topography of the Alps and the influence of the Atlantic, the Mediterranean, and the Eurasian continent on the one hand, and, on the other hand, by its embedment in the global circulation of the mid-latitudes which is strongly influenced by changes in the Arctic and the stratosphere. Regional climate conditions are, moreover, determined by the topography of the Alps and by regional feedback mechanisms (such as between the soil and the atmosphere) which cause the Alpine region to be more sensitive to climate change than the rest of Europe.

Biogeochemical cycles and changes in these cycles resulting from anthropogenic influences are important for the regional and global climate. Numerous questions in climate change research require research of meteorological or biogeochemical processes. However, interdisciplinary research projects often lack the capacity for this kind of research due to time and financial constraints.

Addressing and solving these issues is nevertheless indispensable for robust climate research. Examples for research questions in this regard include precipitation intensities at higher temperatures (greater increase than to be expected according to the Clausius-Clapeyron relation) or the effects on Northern Hemisphere weather types resulting from retreating Arctic ice.

3.1.2 Extreme Events

The public, climate impact research, and decision makers frequently request information on changes in the occurrence of extreme events, not least because such events often cause high costs. At the same time, extreme events are among the aspect of the climate system with the highest uncertainties. Small-scale phenomena are currently neither satisfactorily measured nor modelled. It is thus no coincidence that the AAR14 contains little information on thunder- and hailstorms, tornadoes, or heavy precipitation events. An important yet still insufficiently examined type of extreme events is compound events, where multiple factors interact and trigger extreme impacts.

In the context of climate change, Austrian research is, for example, faced with the following questions: What risks do extreme events in the current climate have? How and why have occurrences changed until now? How strongly has climate change impacted on recent, more pronounced extreme events? Which future changes are to be expected in the occurrence of extreme events? What are the associated uncertainties?

Fig. 2

Profound process understanding is essential for addressing these questions. Future research tasks – also in terms of interrelating different sectors – therefore include the improvement of analyses of past events and developments, making better use of indirect information, and improving the simulation of small-scale phenomena in climate models.

Downscaling procedures in particular need to be further developed in order to simulate both changes in the occurrence of extreme events as well as extreme events which have not yet occurred.
Another significant question in this context is the predictability of extreme events, which is of crucial importance for disaster preparedness and management (for extreme events see also chapter 3.6.6).

3.1.3 Predictability

An important goal of climate research is to improve the understanding of climate system predictability and to advance climate forecasts.
In the given context, there are several aspects to predictability:
(1) making forecasts for the following season or decade based on the climate system's current state;
(2) climate change resulting from changes in the radiative forcing, especially from anthropogenic greenhouse gas emissions;
(3) changes in the regional climate due to global climate change.
Predictability is inextricably linked to uncertainties.

3.1.4 Improved Data

Measurements are a key foundation of (natural) scientific research. Of particular interest for climate research are, for instance, long-term measurements and attempts at making pre-digital data available. The current section addresses aspects which go beyond routine measurements. For further remarks on the latter see also section 3.1.4.1.

3.1.4.1 Measurements (Higher Density, Frequency, and Number of Parameters)

In general, ample high-quality climate data in the narrow sense are available in Austria, including a dense measurement network and long-term measurement series, some of which date back as far as to the 18th century. However, a denser distribution of measurement stations is still necessary, as is its expansion in spatial terms and regarding measured parameters. Especially at high altitudes, only few measurements stations exist, particularly for measuring strong winds, and only a very small number of stations measure all parameters necessary to calculate a complete energy balance of the Earth's surface, even though the energy balance constitutes an essential parameter in all local climate issues.

A related necessity is that of measuring the spectral albedo. Austria especially lacks soil moisture data. There are hardly any routine recordings of flows and vertical profiles of meteorological parameters in the micro- and mesoscale range. On the issue of increasing the density of measurement networks in mountain regions see chapter 3.2.2.

It would be important to extend the measurement network for air-chemical parameters (such as greenhouse gas and aerosol concentrations). This would particularly benefit research in bioclimatology and the quantification of emissions from natural systems and would, moreover, provide a basis for quantifying interactions between the climate and the environment.

Fig. 3

Remote sensing-based climate observation systems are gaining importance in supplementing (not replacing!) validated station data. With few exceptions, the respective data are not processed in Austria. Many standard algorithms applied in analysing, for instance, wind profiles based on satellite data or surface temperatures are only to a limited extent suitable for mountain areas. Hence there is an increased demand for research, development, and measurement in this area. In expanding the measurement network, new requirements such as data for the use of renewable energy must also be considered. Regardless of how dense and sound a measurment network may be, the validity of measurement data remains limited and must be taken into account.

3.1.4.2 Avenues for Experimentation

Experiments cannot be confined to models. In order to explore basic relationships – especially under difficult boundary condition – experiments must also be conducted in nature. This requires micro measurement networks, such as for the parameterisation of flows or to gain a more comprehensive understanding of the boundary layer in mountain areas.

3.1.4.3 Expanding Paleo Data

Currently, paleoclimatology mainly draws on proxy data that provide information on summer periods. Extending proxy data to other seasons and other climate elements could allow for improved chronologies and increase the understanding of both variabilities and processes. Descriptive information and historical records (data recovery) provide a further source of historical climate information.

3.1.4.4 Exploiting Untapped Potential

Numerous existing time series need to be digitised and homogenised so as to make them accessible to research. In many cases this requires developing appropriate methods (for instance in the area of meteorology) for data with daily or sub-daily resolution.

In Austria, the various measurement networks are operated by different institutions largely independently of one another. However, systemic analyses require as many parameters as possible to be measured and observed (across disciplines), at least at core measurement locations. Synergies may also arise with measurement networks operated or data collected in the context of impact or adaptation research.

3.1.4.5 Validation of Observation Data

Observation records are usually recorded under changing conditions and tend to be statistically processed.This is especially true for gridded datasets derived from station data.

These datasets must be validated for their intended use.

3.1.5 Model Improvement on All Scales

3.1.5.1 Reanalyses

Reanalyses – i. e. measurement data that are gridded and analysed by use of models – are performed at the interface between measurements and models. In both atmospheric and impact studies, reanalysis fields extend the climate dataset into the past. At the same time, they support validation of models and parameterisations. The major European climate research centres are currently developing regional reanalyses for Europe. The latter need to be checked for consistency with actual observations in the Alpine region, also in terms of trends.

3.1.5.2 Improving Models, Consideration of Additional Processes, Systems

Climate models can be used to generate climate projections and for model experiments that improve process understanding. The Austrian climate community themselves do not operate a global climate model (GCM) but rely on internationally available model results. This is reasonable, yet a co-operation between users and model developers or operators should nonetheless be established.

Such an exchange is necessary to improve the representation of mountain climates in GCMs as well as to foster an improved understanding of the limitations and uncertainties of GCMs and their impact on simulations of regional climates.

The various regional modelling approaches applied in Austria (dynamical and statistical downscaling, including synoptic downscaling) need to be further developed. Such further development is especially necessary with regard to the specific challenges posed by Austria's topographic peculiarities, but also regarding urban climate modelling.

The relatively new method of inverse modelling used to enhance the interpretation of measurement data also requires further development.

Regional modelling should be carried out in close co-ordination with the international CORDEX activities. This holds especially true for the creation of high-resolution regional climate model ensembles. Key questions address the reasonable temporal and spatial resolution of processes and the levels of model complexity for various applications: Which processes can be adequately represented by parametrisation in the context of which considerations; which processes must be explicitly resolved by a certain model, and where do feedbacks prove essential? To what extent can models of lesser complexity provide valid answers?

Increasing the resolution of small-scale climate models is advantageous. It, however, requires improved parameterisations (regarding, for example, convection, cloud formation, snow melt, the planetary boundary layer, turbulence), better descriptions of boundary conditions (land use, soil moisture, etc.), and observations suitable for the validation of model results (see below).
Remaining problem areas include numerical approaches in very steep terrain and the formation of inversions, both characteristic feature of numerous Alpine valleys and basins.

Against this backdrop, statistical modelling also gains significance: To what extent can cost-effective statistical models generate valid representations of complex local climate processes and their response to climate change?

Snow cover is an important factor not only for the Austrian climate but also for several of the country's economic sectors. However, snow physics incorporated in regional climate models has proven inadequate. This applies to melting and sublimation processes as well as to the downward shift of the zero-degree line observed during snowfall in alpine valleys.

3.1.5.3 Uncertainties, Evaluation

Research must aim at the most comprehensive quantification of uncertainties possible (especially regarding extreme events) and strive to reduce such uncertainties. Comprehensive quantification is important to avoid overly optimistic estimates of climate change. It is important to distinguish between different sources of uncertainty. Dealing with uncertainties and analysing their relevance for scientific disciplines that work with climate model data requires thorough investigation and transparent communication.

Evaluating the results of climate models should also include the representation of relevant processes. On the small-scale, this requires special-purpose measurement networks.
The evaluation of model chains (for instance of meteorological models and models of biogeochemical cycles or dynamic vegetation models) poses a particular challenge.

3.1.5.4 Model Coupling, Feedbacks, Consistency

Further developments are required in the fields of dynamic and statistical downscaling and couplings thereof. The modelling of feedback effects with the soil, the biosphere, or geochemical processes poses a particular challenge.
Model Chains of complex, (mostly) high-resolution models from different disciplines requires close verification of the models in question.
In this context, it is necessary to determine whether the output of one model represents viable input for another. This not only applies to the level of format but also to the consistency of the respective underlying assumptions, resolutions, etc.
Accessible, validated model chains that address a variety of questions could help prevent inconsistent model chains.

3.1.6 Interface between Climate Research and Climate Impact Research; Interaction of Anthropogenic and Climate-Induced Changes

The interface between climate research and climate impact research needs to be substantially improved. A close dialogue with the users of data must be developed, ranging from project development via data generation and application to the interpretation of respective results (see also chapter 3.6.3).
Statistical correction methods must be evaluated and advanced. Furthermore, alternative ways of modelling beyond top-down ensemble modelling

should be explored, such as the simulation of regional narratives describing specific worst-case scenarios as a basis for climate change adaptation.
At present, interactions between changes that are climate-relevant but non-climatic (such as climate-induced changes in the vegetation cover, of irrigation, or in land management practices) are hardly taken into account. They may, however, be relevant to issues of vulnerability, adaptation, or greenhouse gas emissions.

Climate- and socioeconomically-induced changes can also have a significant influence on past measurements which has to be accounted for when analysing trends. Where required, they also need to be considered in terms of changing boundary conditions when modelling the future climate (see also Section 3.2.1).
Finally, but importantly, it is necessary to examine the relevance of climate-related changes in comparison to other anthropogenic developments.

3.1.7 Climate System Thresholds and Tipping Points

It is known that in the past various climate system components or phenomena were subject to abrupt and, as regards human timescales, partly irreversible changes. The possibility that such tipping points may occur in the future can currently neither be dismissed nor affirmed. Investigations of the abrupt climate changes during the Pleistocene could improve process understanding.
An increase in temperature will, however, doubtlessly increase the probability of abrupt future changes.

The fact that established models are often unsuitable for identifying such processes renders this research area both difficult and important. Regardless of their probability, potential impacts on Austria would certainly be worth investigating. Climate change may trigger tipping points not only in the climate system but also in other (such as natural, political, economic, and social) systems (see chapter 3.2.3).
Such processes imply enormous impacts on human civilisation, and in adherence to the precautionary principle they must be taken into account when making political, economic, and societal decisions.

3.2 Research Area II: Impacts On Society And The Environment

Research on climate change impacts and adaptation should always be embedded in a local context and relate to current societal conditions, transformation processes, and socio-economic as well as political developments. Thus, the analysis of climate change impacts and adaptation should, likewise, put a focus on local and regional specificities. Risk, risk management, or resilience can serve as central, connecting themes in this context.

3.2.1 Levels of Theory and Methodology

3.2.1.1 Methods for Overcoming Spatial (Local to Global), Temporal (Past to Future), and Causal (Cause / Effect) Discrepancies

Both climate change and the processes triggered by it are characterised by various scale transitions (spatial, temporal, and causal).
Levels of political decision-making and policy cycles must be considered in this context. An improved understanding of these complex relationships requires appropriate model concepts and corresponding methods.

A related issue is that of downscaling and upscaling within and beyond individual fields of knowledge. All analyses concerned with the context at hand can benefit from being liked to economic impact models, so as to quantify sectoral and economic effects. In many cases, what needs to be clarified is whether isolated surveys or studies can be generalised. This means identifying the criteria case studies must fulfil to make their results transferable.

3.2.1.2 Methods That Take into Account Human Influence and Climate-Induced Changes (Soil, Vegetation, Land Use)

Virtually every natural process and system is influenced not only by the climate but also by human actions (especially utilisation and management practices).Both these influencing factors are reflected in observation and measurement data.

The distinction between individual influences can, in fact, be a considerable challenge and is often not satisfactorily achievable. Human interventions must be taken into account when projecting future developments in climatic scenarios (see also chap. 3.1.6). Moreover, both global climate change drivers and human behaviour constitute strong influencing factors regarding the impacts of climate change on human-environment systems.

Fig. 4

Methodological approaches that equally acknowledge both factors are a requirement for the better understanding of this complex interplay between the various drivers/actions and the respective reactions. Such an understanding thus forms the basis for identifying measures for dealing with climate change impacts on human-environment systems.
Especially in the societal sphere, demographic and socioeconomic change as well as changes in political conditions constitute important influencing factors for future developments that need to be more strongly considered at local, regional, and global levels.

3.2.1.3 Improving Process Understanding

In many cases, individual disciplines still lack process understanding, which inhibits reliable analyses of the impacts of changing climatic conditions (climate penalties).
This applies almost universally to all disciplines and concerns, inter alia, the identification of climate-sensitive ecosystem types; key physicochemical and biological processes in the soil which will be affected by changes in temperature and water balance; and social as well as economic processes and their analyses with regard to thresholds, tipping points, and cascade effects. Depending on the specific scenario, different processes are expected to prove dominant. Even though climate dependencies are generally known in some areas (for instance regarding the landscape relief –relief sphere), actual past and future climate change impacts have hardly been investigated.

Areas of specific interest for Austrian climate research are the identification of self-reinforcing processes and the analysis of a system’s buffering capacities and threshold values prior to the occurrence of significant changes or tipping points.
Changes in a specific component of one system can trigger cascading changes in other systems. This can either have a stabilising or an intensifying effect or may draw ever wider circles.

Since the ultimate aim is to improve system understanding, interdisciplinary scientific co-operation is a vital factor in addressing these issues.
A system's thresholds and tipping points are of particular importance regarding both gradual, systematic changes and extreme events. They define accuracy requirements for the individual disciplines and are a precondition for the correct representation of future scenarios in the related research fields.

3.2.1.4 Improving Models on All Scales, in All Areas, and at Their Intersections

Both models and their results need to be analysed in great detail. They can contribute to the validation of facts, the understanding of processes and systems, and may constitute an integrating factor in interdisciplinary approaches. The identification of suitable application areas for the models requires a precise description of the implicit model assumptions.
In some fields of knowledge, there is still a general lack of models, while in others, existing models are in need of significant improvement. Some research fields, such as ecosystem research, consider it promising to refine methodologies that combine model formulation, simulation, and empiric experimental approaches.

3.2.2 Data, Measurements

3.2.2.1 A Concept for Systematic and Systemic Monitoring across all Areas and Sectors

It is clearly necessary to advance systematic recording of climate change impacts in Austria.
So as to create a basis for decision-making processes regarding climate change adaptation, it is necessary to develop and implement a concept for monitoring climate change impacts in all areas of the natural environment.

In order to facilitate systemic statements, it would be beneficial to concentrate on the implementation of representative high-quality core measurement stations to which, for instance, special measurement networks could connect. These stations ought to be operated on a long-term basis and should fulfil the requirements for collecting data on all permafrost-relevant parameters (such as temperature or conductivity). If possible, they should, moreover, facilitate supplementary measurements of climate parameters as well as the observation of additional parameters (regarding, for instance, vegetation). The same applies to monitoring in the area of biodiversity and nature conservation. In addition, monitoring and data storage systems of economic impact data are to be improved and made available.

The establishment of test areas in the vicinity of settlement areas appears to be essential with regard to data of economic impacts, as it would help to better understand how large parts of the population are affected. Furthermore, the extent to which the resumption of suspended monitoring, or entirely new concepts (such as methane production from landfills) could contribute should be reviewed.

Fig. 5

Model results can provide information on where climate-induced changes appear early or are particularly pronounced. This should be considered when planning measurements or measurement networks. Two-thirds of Austria's land area are covered by mountains. At high altitudes, the measurement network for collecting meteorological as well as hydrological data/parameters is considerably less dense than at lower altitudes. Thus, enhanced monitoring could significantly improve the understanding of how the climate change impulse and its impact on natural systems are connected.

3.2.2.2 Establishing Representative Test Areas (Monitoring Climate Impacts)

So as to better understand the complex interaction between direct, primary, and indirect climate change impacts, it is necessary to establish and operate test areas for recording climate impacts.

This applies to mostly natural, untouched human-environment systems as well as to systems more strongly influenced by human action. It also corresponds to the spirit of the LTSER (Long-Term Socio-economic and Ecosystem Research) Initiative. Austria plays a leading role in this context. The potential benefits of such a system ought to be used to its best advantage and should be extended to further innovative areas.

Fig. 6

3.2.3 Subject Areas (Basics)

3.2.3.1 Impacts of Extreme Events (Variability)

A large number of results yielded by scenarios of climate change – and thus also of future climate change impacts – are concerned with changes in mean values. This is despite the fact that extreme values (minima/maxima) and their temporal distribution are actually much more significant for subsequent processes and for how society can and should deal with climate change challenges and impacts.

However, sustainable decisions and the development of climate change measures (such as designing protective structures in natural hazard management) must be based on information relating to impacts of extreme weather events (heavy rainfall, drought or heatwaves) and/or extreme impacts of less extreme weather events, which are, for instance, caused by land use changes.

The assessment of the impacts of extreme events on society, human health, and the economy would therefore benefit from an improved understanding of the impact of framework conditions on post-extreme-event recovery and reconstruction processes. A better understanding of the respective time scales would, likewise, be desirable.

3.2.3.2 Identifying Climate-sensitive Habitats, Protected Areas, Species, the Interactions between Them, and Their Ecosystem Services

The susceptibility/vulnerability of reaction systems plays a crucial role in the context of climate change impacts. The development of appropriate measures for dealing with said impacts requires the identification and investigation, for example through ecological monitoring, of human-environment systems which are particularly climate-sensitive, that is to say vulnerable.

This may involve the concept of ecosystem services which, in turn, also needs to be analysed with regard to its ethical and cultural implications.
The following approaches have proven advantageous both in the context of generating the appropriate data series on various scales and for the validation of anticipated changes: established biodiversity research; an increased use of technological innovations (for example in the field of remote sensing); habitat modelling; and citizen science.

3.2.3.3 Climate Change as a Trigger for Conflicts of Interest

Climate change can trigger conflicts of interest in both nature and human society (for example between individual and societal and/or present and future interests). In order to successfully tackle climate change challenges, it is important to make these conflicts of interest explicit. This, however, requires systemic considerations across different spatial and temporal scales.

3.2.3.4 Climate Change Impacts on Geomorphological (Gravitational Mass Movements, Glacial, Periglacial, Fluvial Processes, and Cascade Processes) and Soil-forming Processes

As compared to other climate impact processes, the understanding of how the driving process of climate change and the impact on geomorphological and pedological process dynamics relate is still far less advanced than average. However, against the backdrop of the interactions with human interests (risks from natural hazard processes on the one hand, and the soil as basis for agricultural production on the other hand), these processes hold an important position in the interaction between the environment and society.

3.2.3.5 Climate Change Impacts on Agriculture, Forestry, and their Greenhouse Gas Balances

In the field of agriculture and forestry, climate change impacts are closely linked to practices in land and soil management as well as to adaptation measures. However, many questions of detail remain unanswered. They concern, among other things, the following issues: changes in the potential of individual locations (supply of nutrients, water balance); the leeway in future forest management, including the short-, medium- and long-term effects of adaptation measures on forest vitality, ecosystem services and the rural economy; future tree species composition as well as locally adapted agricultural crops and production methods; tillage; the consequences of measures to reduce greenhouse gas emissions (CO2, N2O and CH4); invasive species; and phytosanitary issues (changes in the occurrence of harmful organisms).
Besides the individual analyses of such issues, integrated assessments and system analyses are constitutive of well-founded risk and resilience assessments.
The repercussions of management or adaptation measures on greenhouse gas emissions, non-greenhouse gas emission effects (non-GHG effects), and on how those affect the climate are of particular relevance.

3.2.3.6 Impacts on the Infrastructure Sector

Climate change-related issues in the infrastructure sector concern impacts on infrastructure itself (such as dam failures, washouts, heat damage to roads, or power supply interruption) as well as impacts resulting from damages to the infrastructure (such as the disruption of supply chains). As infrastructure is primarily affected by extreme events, reliable information on the future development of these event is of vital importance for this research area (see chap. 3.2.3.1).

Analysis of past events, which is equally important, depends on the availability of appropriate, comparable data (see chap. 3.6.6).
However, given that accuracy requirements are carefully estimated, a considerable extent of information relevant to this context can also be extrapolated from already existing knowledge. Yet, system analyses for assessing the impact of infrastructure damage in Austria (such as the effects of a prolonged blackout) remain sparse.

Consistent with chap. 3.2.1 (Levels of Theory and Methodology), analyses of impacts on the infrastructure sector also require scenarios of future demographic developments, traffic development, and dependencies on power grids vs. stand-alone installations.

3.2.3.7 Climate Change Impacts on Human Health and the Social Fabric

Many questions concerning issues of both direct and indirect climate change impacts on human health have not yet been answered.
These concern, for example, seasonal shifts in health problems and illnesses (such as allergies or colds), the occurrence of previously non-"native" diseases as a result of altered conditions for vectors and pathogens, or the quality of drinking water.

In this context, the aim is to not only find technical but also organisational solutions to the problems at hand. Further relevant issues in the health sector are mutual aid arrangements (for instance during heatwaves) or the adaptation of public spaces.
The expected increase in urban population poses additional problems (such as densification or the increasing "urban heat island effect").
The socio-economic aspects of climate change remain under-researched. These include, for instance, indirect climate change impacts on low-income population strata (such as increasing food prices or fluctuating energy costs) as well as migration issues ("climate refugees").

3.2.3.8 Further Climate-sensitive Areas

In addition to climate change impacts on the areas of agriculture and forestry, ecosystems and biodiversity, infrastructure, human health, and the social fabric, the Austrian national strategy for climate change adaptation also identifies other directly or indirectly climate-sensitive areas. These are energy supply and demand, water supply and sanitation, production and trade, tourism, urban and green spaces, spatial planning, transport, natural hazard management, and disaster management.

While research results on incremental adaptation (i. e. reinforcement of pre-existing adaptation measures such as flood protection) are currently available for most of the adaptation strategy's fields of application, research on transformative adaptation (new forms of adaptation) still remains a research lacuna. Further research requirement also concerns the interactions between adaptation measures in different fields of activity, such as competition for water between irrigation and cooling. As planning horizons in some sectors are not long enough to adequately address long-term issues (such as climate risks), sectoral analyses of

Fig. 7

the respective weather sensitivities should also be promoted in order to raise problem awareness.
Since short-term effects of weather variability are often more easily comprehendible, they might serve as an incentive for investigating the impact of climate variability on respective sectors.

3.2.3.9 Climate Change Impacts on Local / Regional Air Quality

Weather conditions determine the concentration of air pollutants via chemical conversion processes (temperature and UV radiation, especially as regards ozone, secondary aerosol and oxidants) on the one hand, and, on the other hand, through diffusion processes (wind direction and speed, mixing layer height).
Regardless of existing knowledge of these processes, it still remains necessary to further investigate the effects of future climate scenarios, especially so in small-scale contexts (such as urban street canyons) and in terms of projected emissions.
This is a complex interdisciplinary task whose findings would have significant implications for, among other things, urban and spatial planning.

As it affects the health and life expectancy of any population, air quality must also be considered from the perspective of public health.
Changes in emission profiles as well as in atmospheric chemistry and the distribution of pollutants may, however, cause hitherto applied and validated air quality markers to become less relevant. Thus, the continuation of epidemiological studies on how air quality affects human health is also relevant in a climate change context.

3.2.3.10 The Detection of Tipping Points in Systems that are Influenced by the Climate

The identification of tipping points in large-scale global subsystems (such as the Indian monsoon) is receiving much attention. This is due to the assumption/concern that, after exceeding a certain threshold, changes in said subsystems will feed back into the global system in an unpredictable manner.

Tipping points can also occur on a much smaller scale and may lead to previously unpredictable impacts and feedbacks (such as rock falls due to loss of permafrost, a subcritical length of the winter holiday season, or temperatures too high for certain types of vines).
Only an improved process understanding of the interaction between climate driver and reaction system (based, for instance, on the joint evaluation of monitoring data) makes it possible to detect and analyse tipping points and thus prevent the collapse of systems.

3.3 Research Area III: Adaptation

Adaptation measures are always tied to local/regional conditions and (unlike technological developments) therefore require area-specific knowledge regarding both natural and socio-political realities.
Specific research questions can be clearly defined on both theoretical and methodological levels. In research that accompanies the actual implementation of measures, the line between research needs and general challenges regarding the clarification of implementation details is, however, blurred.
Criteria that determine methods in terms of their scientific quality are therefore all the more important. In addition, the development of adaptation strategies must include a comprehensive and methodologically sound quantification of possible effects or, more specifically, of risks and uncertainties. Like other countries, Austria has adopted an adaptation strategy for most climate change-affected sectors.

These strategies set specific targets and define concrete measures for climate change adaptation within more or less precise timeframes.
Scientific questions pertaining to the implementation and continuous update of said strategies are diverse. Appropriate research results should thus facilitate the continuous update, improvement, and expansion of adaptation strategies.

3.3.1 Levels of Theory and Methodology

3.3.1.1 Adaptation Theory

Climate adaptation, just like climate protection, necessitates long-term, complex and sometimes very profound changes in society and the economy.
Many recurring questions in climate discourse (such as addressing relevant time horizons) are highly relevant to the field of climate adaptation from an ethical and a scientific point of view.
The interactions between climate change adaptation and mitigation raise further scientific questions, and, in addition, both the development of adaptation measures and their evaluation play an important role.
Efficient models for the analysis and explanation of adaptation issues based on economic, political, and social theory are therefore necessary and subject to intensive research.

Such models must delineate the possibilities and limits of adaptability.
Increasingly accessible, spatially highly-resolved data on expected climate changes are the basis for the issues discussed below, except for those (equally noteworthy) examples that relate to robust adaptation.

3.3.1.2 Action Research, Participation

Both participatory small-scale assessments of vulnerability and the participatory development of adaptation strategies depend not only on theoretical approaches to adaptation but also on practice-oriented methods. The scientifically sound examination of complex problems posed by climate change adaptation requires, among other things, the further development of action research methods (which particularly befit problem-solving-oriented research), appropriate participatory concepts, and inter- as well as transdisciplinary research approaches.

Governance analyses, likewise, offer important new insights through examining social co-ordination processes with regard to all relevant interest groups. In this context, the different approaches pursued by citizen science and responsible research also deserve particular attention.

3.3.1.3 Downscaling and Upscaling Courses of Action

It is necessary to promote the development of methods for downscaling and upscaling. This regards not only (climate) data, but also the analysis of how strategies, methods, adaptation, and monitoring measures take effect at, and affect actors on, regional and local levels and vice versa.
When conducting case studies with the aim of deriving generalisable results that engender a process of mutual learning, a critical set of methodically co-ordinated case studies conducted across different regions, sectors, and populations is required.
This, in turn, depends upon the development of evaluation criteria for measuring "successful" adaptation. These criteria should subsequently be used for the verification of effectiveness and for cost-benefit assessment in ex-ante and ex-post studies (i. e. policy evaluation studies).

3.3.1.4 Maladaptation

Maladaptation – i. e. measures that do more harm than good, or in the context of which an adaptation benefit counteracts a mitigation goal – are an important topic in adaptation research, and the investigation of unintended consequences of adaptation measures is an important research undertaking.

This issue is often linked to questions concerning a measure's temporal and spatial scales and governance structures (see also chap. 3.4.4 Interaction between Mitigation and Adaptation).

3.3.1.5 Limits and Effectiveness of Adaptation

As in the case of climate system tipping points (see chap. 3.1.7), it is also necessary to investigate the tipping points of socioeconomic systems, for a certain extent of climatic change (such as change in temperature or the shift of climatic zones) marks the limits of adaptability.

These limits may, for instance, be determined by the types of adaptations planned (green or grey adaptation), available resources, public acceptance, or the level of existing knowledge. Appropriate analyses, which include related economic costs and benefits, are not available for Austria but would be necessary.

3.3.2 Level of Implementation

3.3.2.1 Research on Integrating Adaptation into Various Policy Areas

It will be necessary to analyse the appropriate prerequisites and required measures for developing a new, transverse policy field of "adaptation". Processes of institutional, actor-strategic, and discursive change must also be determined in this context.

Processes that may engender more open approaches towards new solutions in planning and policy making processes (across all policy areas affected by adaptation) need to be identified. It is, moreover, particularly relevant to seek the dialogue and discourse with actors from both the private business sector and society at large. In so doing, the social sciences – such as political science, sociology, anthropology, or psychology – should play an increasingly important role and must therefore be fostered.

3.3.2.2 Societal Contextualisation of Climate Change, Climate Impacts, Adaptation, and Vulnerability

Societal contextualisation is necessary in order to cope with the complexity and multi-dimensionality (social, temporal, spatial) of climate impacts and adaptation. This includes, for instance, the analysis of gender roles within the context of climate change.

Climate-related processes and their (presumed or proven) temporal changes do not necessarily have to serve as the starting points for socio-scientific considerations. The latter may just as well focus on societies or societal processes such as efforts to protect the climate and adapt to apprehended climate change.

Thus, the research needs of implementation-oriented vulnerability research are not restricted to technical questions but also include socio-economic issues such as the investigation of the tangible success of adaptation measures.

3.3.2.3 Assessment and Comparison of Measures

This field includes the further development and increased application of methods (such as multi-criteria analysis or robust decision making) that facilitate a comparison of the impacts of adaptation measures, financial and otherwise.

Municipalities and regions are often forced to choose between different adaptation measures (such as technical flood protection for a community, relocation from flood areas, water management measures, or detention reservoirs). These not only require differential funding, but also provide different levels of protection, burden different groups to greater or lesser extents, or become effective over different timescales. In addition, the actual success of implementing adaptation strategies should be analysed and, if possible, also quantified.

Fig. 8

Appropriate research should furthermore identify beneficial and disadvantageous factors in the implementation of adaptation measures as well as requirements for successful adaptation. It appears particularly worthwhile to aim at making better use of international comparisons by analysing successful strategies with regard to their general success factors. Thus, said factors could also be integrated in the local context.

3.3.2.4 Operationalising Recommendations for Action

Activities that may form part of action research are generally concerned with identifying opportunities for action. However, they also involve making recommendations in support of both decision-making processes and the measures themselves.

This renders capacity building an integral part of research projects. The evolving field of "knowledge broking" has the potential for generating important synergies between science and policy/application, but also needs to be critically reviewed.

3.3.3 Monitoring, Documentation

Adaptation measures are sometimes undertaken at a private level; at other times, they result from local council decisions or from resolutions issued at higher levels. As mutual learning is a necessity, concepts for documenting adaptation measures ought to be developed. Such concepts should, moreover, provide a means for determining and evaluating the extent to which adaptation measures meet their objectives.

This holds particularly true in the case of model regions for adaptation. With regard to such regions, and also to potential upscaling, both general and specific constellations of action need to be considered.

3.4 Research Area IV: Mitigation

The reduction of greenhouse gas emissions (GHG emissions) and the increase of greenhouse gases stored in the soil and in biomass constitute the most important anthropogenic contributions to climate stabilisation.

The industrialised countries' transition towards virtually zero greenhouse gas emission by the mid-21st century is imperative for meeting the Paris Climate Agreement objectives of keeping the increase in average global temperature well below 2°C above pre-industrial levels and making efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

A further aim is to reach a global balance between anthropogenic greenhouse gas emissions from sources and the reduction of such gases by sinks. This will require action in the following areas essential for effective climate protection: eco-sufficiency, increased energy efficiency, transition to low-carbon energy sources (typically renewable), greenhouse gas reductions of non-energy related emissions (especially in agriculture and forestry), and an increase in sink capacity.

There is a need for research across all areas regarding scientific, technological, and particularly socio-economic issues. It must be noted that all of these issues need to be investigated within a mutual context. This investigation should, moreover, include questions concerning lifestyle as well as social and individual values (see also chap. 3.5.1).

3.4.1 Technological Development and Mitigation Options by Sectors

The significance of mitigation measures cannot be assessed with regard to technical and economic characteristics alone. About two-thirds of all global and Austrian greenhouse gas emissions result from the use of fossil fuels which are a core element of the current economic system.
Both an analysis of the energy system and potential options for change relate to the issue of energy services important for economic welfare (such as temperature-controlled housing or mobility).
Current research on this issue should be intensified and undergo model-based development.

Interventions in the energy system affect, in a variety of ways, both specific economic sectors and public as well as private expenditures.
Generally speaking, new technologies can only spread when society accepts them, while the introduction of a new technology can, in turn, cause social and economic transformations.
Renewable energy technologies – such as solar and wind energy or biomass – cause changes in the cultural landscape as they depend upon new specialists and special knowledge, lead to changes in energy imports and related geopolitical dependencies, and influence tax revenues as well as subsidy structures. Their decentralised character changes the spatial and institutional structures of both the economy and society.

Expanding renewable energy technologies requires new infrastructure and leads to production and consumption patterns which are distinguishable from those of centralised power generation technologies such as fossil or nuclear energy (see also Research Area V).

3.4.1.1 Technological Development

The Science Plan is not concerned with technological development in terms of research or advancements in the field of climate-friendly technologies (i. e. mitigation technologies) as such. Rather, it focuses on observing the status quo as well as future trends, especially in the fields of energy demand (for housing, mobility, production, etc.) and supply, but also the assessment of such trends in terms of social risks and transformation (including geo-engineering).

Fig. 9

Mitigation technologies have been analysed in a parallel process as part of the “Dialog Energiezukunft 2050” strategy process under the auspices of the Austrian Ministry of Transport, Innovation and Technology. The results are complementary to those of the Science Plan.

The Science Plan does, however, include questions concerning the potential renewable (and possibly also alternative) energy sources poses under changing climatic, economic and social conditions. It also addresses questions regarding agricultural technologies and increasing energy efficiency.

3.4.1.2 Lock-in Effects

The advancement of technologies involves the risk that mitigation measures which were at one point the best possible answer to a given problem may become liabilities. This is the case when more advanced technologies could, in fact, save more GHG emissions, while the end of the previous technology’s lifecycle has not yet been reached. Developing concepts for how to anticipate and possibly avoid such lock-in effects is an important task.

3.4.1.3 Rebound Effect

The so-called rebound effect, which relates to the actions of individuals, occurs when (financially advantageous) instances of saving energy or reducing GHG emission are cancelled out by additional energy consumption or increased GHG emissions elsewhere. Even though the rebound effect has already been scrutinised, there is still a need for further research into how it relates to common lifestyles and the current growth paradigm.

3.4.1.4 Energy Production and Demand; Natural Resources

Data availability for the energy sector is insufficient: spatial high-resolution data on the sustainability as well as physical, technical, and economic potential of renewable energy sources are lacking, as are continuously updated databases for cost developments of related technologies.
Scenarios under different subsidy options would also be necessary, as would options for fostering higher cost transparency (such as the internalisation of external costs).

In order to provide a better basis for policy making, investigations on the topic of energy demand and production must include empirical studies as well as the consolidation of modelling approaches. This includes research on technical and institutional hindrances to the improvement of energy efficiency or possibilities to limiting and/or sustainably meeting expected future electricity demands. It also encompasses research into the cost-effectiveness and social compatibility of various systems promoting a shift towards renewable energy sources (such as subsidies, regulatory law, fiscal measures). Broadening energy transformation research, including the systematic comparisons of results derived from models as well as from energy and emission scenarios (such as benchmarking and multi-model comparisons or the analysis of results from ensemble scenarios) could render research results considerably more robust and thus increase credibility.

Research issues include public acceptance of, for instance, smart grid technology or ubiquitous sensing as well as questions regarding the significance of potentially disruptive technologies of relevance to the energy transition (such as battery integrated electromobility, autonomous driving, high efficiency European DC networks, energy service companies, mobility services, or innovations regarding demand such as demand-side management).

It is, moreover, necessary to investigate the relationship between energy targets, climate targets, and other aims of energy policy making at national, EU, and international levels (security of supply, competitiveness and affordability).

3.4.1.5 Mobility Systems and Mobility Behaviour

The transport sector is responsible for about one quarter of greenhouse gas emissions in Austria and worldwide.

Various measures can be implemented to reduce emissions across the transport sector: the avoidance of mobility pressure through appropriate settlement structures; traffic regulation and planning, technical measures; "soft measures" such as information, education, economic incentives; and fiscal measures.

Fig. 10

Despite the successful implementation of such measures in all sectoral areas, further research remains necessary,

regarding, for instance, the analysis of target realisation or the public acceptance of individual measures. Moreover, effects of new technological developments such as autonomous driving or sector coupling (electric vehicles as temporary power stores) combined with other trends such as vehicle sharing should be investigated.

3.4.1.6 Land Use and Spatial Planning

Since questions concerning land use as well as spatial structure and planning, which also include aspects of governance and decision-making structures, are not specific to any one economic sector, current research does not particularly focus on these areas.

Climate-related issues include systematic interactions between (changes in) land use (incl. land management or land use intensity) and land cover changes. This includes resulting greenhouse gas balances (sources and sinks).

Improved information bases could also foster better estimates of both costs incurring from and the potential of GHG reduction through land use change.

The relationship between population growth, migration, rural exodus, urbanisation, and climate change constitutes a further research lacuna.

Appropriate research should also consider the importance of property values and issues related to the distribution of property. Decisions in the area of spatial planning tend to have long-term effects and can heavily impact resource consumption and land use as well as traffic emissions.

Comparative studies on the wide range of legal provisions and practices in different municipalities, regions, and countries afford a good opportunity for determining and drawing conclusions from transferable best practice examples.

3.4.1.7 Agriculture and Forestry

Agriculture and forestry can significantly contribute to climate change mitigation via the forms of tillage (organic rather than conventional farming), forest management (such as deforestation or rotation times), and the production of biomass for energy generation. In this context, future research should investigate the interaction between the carbon balances of agriculture and forestry and bioenergy as well as the utilisation of biogenic resources for the production of materials (for instance in bioeconomy, construction, or the paper industry).

Another question to be considered is how carbon benefits per hectare of organically farmed land, for instance, relate to respective disadvantages resulting from increases in land requirements. Further open research topics include the reduction of GHG emissions from livestock husbandry (especially meat and dairy production) and how this relates to animal welfare and animal health (also against the backdrop of changing climate conditions and the possible spread of new vector-borne diseases).

It would, moreover, be advisable to systematically record changes in the area of food demand (such as the relevance of vegan and vegetarian lifestyles, the market for regional and organic products, or the impact that assessing a product's life-cycle can have on consumer behaviour). Efficient and effective ways of avoiding food waste across the entire value chain should also be more thoroughly investigated.

Fig. 11

Since agriculture counts among the sectors that are strongly affected by the phasing out of fossil fuels, questions of food sovereignty and security within the context of climate change constitute another field for extensive research.

3.4.1.8 Infrastructure and Its Role in Resource Consumption

Infrastructure determines resource consumption and greenhouse gas emissions in many ways and affects lifestyles as well as the quality of life.

Especially long-lived infrastructure (for instance in the transport sector) can trigger lock-in effects and hinder the transition towards a low-carbon society and economy.

Thus far, no substantial research has been conducted regarding systematic infrastructure surveys or potential scenarios for a conversion towards a climate-friendly infrastructure, including funding and potential obstacles.

Infrastructure's resilience to extreme weather events and their impacts is a particularly important issue but has nonetheless thus far remained insufficiently investigated in Austria.

3.4.1.9 Buildings

Although the building stock has been relatively well studied, it will be necessary to improve the data situation for non-residential buildings and their energy consumption. How existing barriers to thermal rehabilitation and the conversion of heating systems can be overcome requires analysis. This particularly applies to urban areas with high population density and a substantial number of historical and listed buildings.

Research and development efforts towards more cost-effective systems facilitating the rehabilitation of buildings in use could significantly improve the refurbishment rate.

3.4.1.10 Financial Sector

The financial sector's relevance for the transition of the economic system towards a sustainable and climate-friendly economy has hardly been studied in Austria. Future research should therefore, firstly, investigate the mobilisation of public and especially of private capital for the conversion of infrastructure, including buildings (for instance via crowd investing, green bonds, or PPP models). Secondly, the topic of divestment (i. e. the withdrawal of capital from climate-damaging investments) as well as its relevance for and impact on Austria should be analysed.

3.4.1.11 Industry

In line with the broad spectrum of industries in Austria, research questions regarding the industrial sector are also highly diverse.

Both technological measures to improve efficiency and measures concerning organisational logistics are required. The latter include issues regarding the organisation of process chains (compare catchphrases such as just-in-time production or "the road as storage facilities") and transport distances in these chains.

Of further importance are aspects of resource efficiency and the connection to the EU Commission's Circular Economy Package, especially since using secondary fuels and secondary raw materials in particular constitutes a key opportunity for reducing GHG emissions. Corresponding relations – including product design, life cycles, and repairability – should likewise be examined. The same holds true for the analysis of the progression of digitisation and robotization in the industrial

Fig. 12

sector (Industry 4.0), the potential these developments hold for, and the impact they have on, the carbon footprint of production. Further objects of research should comprise the potential transition towards renewable raw materials ("bioeconomy") and its possible impact on the carbon footprint, as well as any negative environmental effects resulting from an increased demand for biogenic raw materials. Obviously, the industrial sector can only achieve ambitious climate goals on the basis of technological innovations.

Planning security is an important requirement for a transition towards fundamentally new processes, especially in the area of energy-intensive industries. The aim is to exploit opportunities for avoiding process emissions (i. e., non-energy-related GHG emissions occurring to a significant extent in current technologies such as cement and pig-iron production).

In this context, research should address new technologies (such as the direct reduction of iron ore by hydrogen) as well as alternative materials and their ecological and economic impact. It is thus necessary to develop scenarios for Austria's pathway towards a low-carbon society, from which robust framework conditions can be derived (see Section 3.5.3).

3.4.2 Policy Level

Technology-driven models of mitigation can only provide limited information about the feasibility of the two-degree target. They can likewise only provide inadequate answers to questions concerning which steps and direction a medium to long term transformation towards achieving said target must follow. Thus, trying to find ways of dealing with the challenges of a changing global climate must also encompass an examination of societal and political systems, which constitutes the core of transformation research.

3.4.2.1 International Aspects; Reducing Emissions Along the Value Chain

As a result of the internationalisation of value chains, the reduction of domestic emissions (decrease in production-based emissions) in some cases leads to an increase in imported foreign emissions (increase in consumption-based emissions). This prompts a need for research into the effectiveness of national and European climate policies in the avoidance of increasing imported emissions, and it is also necessary to assess the divergence between domestic and imported GHG emissions from land use.

3.4.2.2 European and National Climate Policy

As an EU member state, Austria can co-determine EU climate policy. This, however, requires independent analyses concerning the effectiveness of short- and long-term climate policy instruments and measures at national and European levels.

Research should, for example, address the question of how appropriate instruments must be devised so as to offer long-term mitigation incentives for companies and households rather than trigger short-term evasive reactions (see also chap. 3.4.1.3 on the rebound effect).

Such investigations can be carried out using sectoral or macroeconomic models or may consist of qualitative political and empirical sociological analyses.

3.4.3 Models

3.4.3.1 Model Improvement

Research in this area needs to improve existing and develop new models for mapping the transition process of economic and energy systems towards virtually zero greenhouse gas emissions for mid- and long-term horizons (2050 and beyond).

This should encompass models based on various scientific paradigms that either map the entire system or individual subsystems.

The development of such models requires the review and modification of implicit assumptions regarding, for instance, market characteristics or actor behaviour.

It will, moreover, be necessary to promote models and scenarios that enhance capacity for dealing with uncertainties and variability.

3.4.3.2 Model Validation

Multi-model comparisons are also gaining importance in the validation of results from socio-economic research.

The Science Plan therefore supports multi-model comparisons for Austria as well as the validation of model results through an ex-post analysis of political realities.

3.4.4 Interaction between Mitigation and Adaptation

Mitigation and adaptation are inherently related, as they are often mutually conflicting or supportive and frequently require the same means.

It is therefore necessary to develop methods for optimising adaptation and its timeous implementation, reducing trade-offs between adaptation and climate protection, and utilising co-benefits.

In addition, the necessity for governmental regulations in contrast to uncontrolled private adjustments and the outcome of these strategies in terms of additional emissions and resource consumption ought to be addressed.
Scientific support of process design in the area of implementing climate change mitigation and adaptation processes could help decision makers draw optimised conclusions from both successful and unsuccessful implementations. This could, in turn, foster capacity building, knowledge transfer, and social learning processes.

3.4.5 Costs of Climate Change and/or Climate Policy

In line with IPCC, the development of integrated scenarios could contribute to establishing a consistent framework for the analysis of climate change and/or climate policy costs. This would, for instance, make it possible to assess the costs of climate change with respect to different mitigation goals.
Such a development would require for Austrian socio-economic scenarios to be consistently derived from already extant national and international scenarios. This process should be conducted with stakeholder involvement.

Past cost-of-inaction analyses have shown a lack of comprehensive quantification of tangible and especially of intangible climate change impacts.
It is therefore necessary to develop appropriate methods that also allow the consideration of intangible and other non-economic values. The analysis of how socio-economic changes (such as demographic or structural changes) influence climate change costs in comparison to costs from changes in climatic exposure would constitute another research objective.

In the mitigation context, the issue of co-benefits has been gaining international significance. This relates to the positive side effects of climate policy measures, such effects occurring, for instance, in the area of human health (through the reduction of classic air pollutants such as particulate matter or NOx) or with regard to the security of supply.
Investigating essential domestic aspects would thus be an important contribution to research. A further research advancement would be to not only analyse the impact of various climate policy instruments (such as subsidies, regulatory law, taxes) on GHG emissions, but to extend such analyses to the national economy (for instance to sectoral effects, employment, national budget, income distribution, or welfare).

It would, moreover, be desirable to evaluate the role of political, economic and / or ethical considerations in the context of allocating climate change and climate protection costs among differently developed and affected regions at national and especially at international levels.

Fig. 13

3.5 Research Area V: Societal Transformation Processes

Since even a wide distribution of "climate-friendly" technologies will not suffice to solve the climate problem in the long term, a broad international debate about the need for a fundamental transformation (or transition) of global societies has arisen. The central issue at hand is to develop a new understanding of prosperity and quality of life (that is, a good life in the broader sense) which is based on a significant decrease in resource consumption (land, materials, water, energy).

For one thing, this would involve a change in current lifestyles (regarding, for instance, consumer or travel behaviour) in conjunction with a shift in the value system. For another, it will be necessary to discard conventional production structures as well as traditional economic and working models and develop new ways and forms of participation.

Such a fundamental and far-reaching systemic transition requires a social debate concerning the question of how a good life should or could be defined it future. It, however, also calls for new forms of interdisciplinary and transdisciplinary research. Even though the necessary social transformation goes far beyond climate change matters, it is impossible to strictly differentiate between the two issues. The Science Plan focuses on climate-related questions. However, since there are still substantial research needs concerning more general questions, the Science Plan must address those, too.
A systematic approach towards general associated topics could yield high transformative potential, and progress on a general level could be a precondition for finding solutions to more specific, climate-relevant issues. On the one hand, research challenges include the determination of reasonable thresholds for resource consumption, primarily undertaken by the natural sciences. On the other hand, research ought to be involved in developing political and social opportunities for a transformation towards a low-carbon society (primarily via the economic and social sciences).
This undertaking is determined by both small, immediately effective steps as well as long-term concepts and strategies.

However, either can only be productive if they address the entire spectrum of the problem.
Specifically, this includes the cultural, social, political, institutional, and economic issues which have led to the present unsustainable patterns of resource use and their perpetuation.

Moreover, regardless of whether small steps are being taken or large-scale transformation concepts are implemented, it is always imperative to determine the political feasibility and improve the practical applicability of the respective processes.

Fig. 14

3.5.1 Sustainable Society

3.5.1.1 Research on Ecologically and Socially Sustainable Lifestyles

Climate policy and sustainability call for changes in the production methods and lifestyles of industrialised countries. This is due to the fact that related resource consumption (resulting, for instance, from consumer or travel behaviour) is not transferable to the lifestyles of nine to eleven billion people. This raises the question of how the material foundations of a desirable "good life" are to be defined.

The wish to increase or at least maintain current levels of prosperity ought to prompt a general debate on the material foundations of prosperity and liveability. What is furthermore required, is an extensive discourse concerning societal values and their material implications (such as resource consumption or carbon footprints).

Such debates and discourse can form the basis for determining indicators for well-being and liveability which would make a helpful contribution to the transformation discourse.

Climate-relevant changes in lifestyle and behaviour include, for instance, the reduced consumption of animal proteins, a shift from material to service-oriented consumption, less and slower mobility, or time prosperity.

All of these factors affect how material resources and space are used and imply cultural change.

Changes in lifestyle and behaviour thus constitute important elements of societal transformation.

3.5.1.2 Values in Society

Societal decisions are based on values and value systems which are, in turn, influenced by existing social, political, and economic conditions.

With regard to the question of how societal transformation can succeed, concepts such as quality of life, environmental or climate justice, and participation (especially in relevant discourses) are becoming increasingly important.

The increasing awareness of, and need for, new value systems are, moreover, illustrated by efforts to establish and apply new approaches to measuring well-being, such as Beyond GDP or the Happiness-Index. This desideratum is also reflected on political and economic levels.

3.5.1.3 Visions of Resource-saving Individuals and Societies

The potential shape and nature of a carbon-neutral society still needs to be outlined to a higher degree of (scientific) precision.

What will people eat? What and how will they work? What will they do in their spare time? How will they live? How will they travel and for what purposes?

Naturally, such questions concern not only the industrialised countries, but are relevant throughout the world. They arise within the context of interactions between different lifestyles and significant differences in resource consumption.

It must be born in mind that new societies are not developed from scratch. Existing physical, economic, and social structures, and infrastructures in particular (for instance in the mobility sector) strongly impact individual behaviour and must therefore be adapted to a resource-saving lifestyle.

For society to accept appropriate adaptation measures, it is necessary to embed their development in a participatory process.

3.5.1.4 Socio-economic Challenges of Transformation

A scientific examination of the transformation process towards a climate-friendly or sustainable society must, in particular, take into consideration a wide variety of issues, ranging from monetary and financial systems, through economic concepts and models, the significance of policy cycles within the context of long-term policy needs, work models, to the legal system.

Despite the fact that short-term solutions adhere to current concepts and paradigms, medium and long-term solutions will have to instigate more radical changes. In this context, it is incumbent upon science to lead and support the exploration of appropriate new pathways.

Work models are located at a point of convergence between economic and social systems.
This highly relevant issue for the transformation process is still under-researched. In addition to employment, other forms of work (such as care work) will gain importance, and topics such as an unconditional basic income will have to be revisited.

Fig. 15

3.5.2 How Can Transformation Be Shaped?

The transformation towards a climate-friendly society must be shaped against the backdrop of a wide range of economic, technical, and legal processes in which globalisation and Europeanisation play a central part.

Thus, transformation processes in society, politics, and the economy must not be explored independently of one another, and it is necessary to acknowledge that the actions shaping these processes must be of political nature in the broadest sense. Thus, following and similar questions are relevant in the context at hand: Which institutions and processes are suitable? Which are available? Which need to be created? What legal instruments are required?

The contributions of individual sectors to achieving the climate target are certainly important. It is, however, likewise essential to take into account the impact of transformation processes – such as the transformation of the energy system – on other sectors, and one must, moreover, consider the dependencies and power relations between individual sectors. As other actors and processes will become more important, the political system faces considerable challenges and needs to redefine its general role in society.

3.5.2.1 Education and Media

Whether climate protection measures are applied and whether social transformation takes place, depends on the respective risks, costs, and benefits as well as on social, cultural, and political factors.
Generating and communicating comprehensive and effective scientific results for climate change consultancy requires a combination of effective climate policies and bottom-up initiatives, both of which rely on an informed and committed public.

This poses various challenges for research:
It seems appropriate to address global societal challenges, including climate change, in both school and university curricula as well as in teacher training and continuing education for university lecturers. This raises questions concerning the practical implementation of appropriate measures that ought to involve pedagogical concepts of knowledge transfer, including the topics addressed in chapter 2.2.
This also involves research into values and value systems and motivational research. With regard to public awareness, science must identify, among other things, the endogenous and exogenous factors which are essential for embedding both the topic itself and topic-related scientific knowledge into the public awareness. Questions concerning key actors, who ultimately determine the effectiveness or ineffectiveness of climate policy, should also be addressed against this backdrop.

This involves issues concerning both traditional media and social media, which impact on their audiences according to different interest-based structures and are determined by different patterns of interest. The dynamic resulting from the interplay between all these factors and networks is also of great interest, since ultimately the self-perception of society is of likewise great relevance.
Important parameters of the interaction between science and politics include, firstly, an action-oriented approach to, as well as the communication of risks and uncertainties (science to politics) and, secondly, an understanding of political realities (politics to science) and of how climate policy needs to be co-ordinated against the backdrop of media, interest, and power structures.
Research in these areas could help improve the knowledgebase upon which policy decisions are founded.

The analysis of reasons for climate change denial and the development of strategies for dealing with this constitute further important research desiderata. These need to be addressed on two different levels: the purely climate-scientific level, which can generally rely on existing knowledge, but may in certain cases also raise new research questions; and on a motivational level, where it is necessary to answer political, sociological and psychological questions.

3.5.2.2 Decision-making in Politics, Economy and Society

The problem of climate change extends to all political, economic, and societal areas and should not be tackled independently of them. It has been increasingly observed that the accessibility of scientific facts does not automatically trigger rethinking processes and that political decisions are rarely made based on such facts. Balances of power and currently dominant economic models often oppose decisions that counteract climate change impacts or attempt to reduce climate change triggers.

Primarily short-term planning in politics and economy is often at variance with the timespans during which global climatic changes can be influenced.
Climate change research cannot simply accept this as a given, but must expand its scope and agendas accordingly. The social sciences can contribute to the explanation of relevant decision-making processes at all levels, down to the individual, and may thus help increase the acceptance and relevance of scientific climate research in all areas.
Jurisprudence needs to address the question of how appropriate future legislation and case law can improve their respective contributions to climate protection and climate change adaptation in Austria, the EU, and at a global level.

3.5.2.3 Integrating Climate Policy-making into New (or All) Policy Areas

Research can accelerate the process of integrating climate policy into other policy areas (especially those of energy, transport, agriculture, and forestry) at a national level (federal, regional, municipal), and it can also foster an integration into general political decision-making processes. However, such an undertaking is also influenced by the power relationships within and between the respective policy fields.

In this context, aspects to be considered include an improved utilisation of synergies, the prevention of trade-offs, and interactions between different instruments and measures (including climate policy instruments, legislation and case law, coordination processes such as climate strategy, climate protection law, but also other sustainability-relevant strategies such as bioeconomy).
Effectiveness analyses of existing and innovative policy instruments as well as monitoring of appropriate measures are required. The recording of long-lasting impacts in order to facilitate learning processes likewise calls for a persistent reconsideration of relevant instruments.

3.5.2.4 Institutions and Governance

A better understanding of political and societal institutions and of governance strategies is central when it comes to improving the potential for re-shaping society. This context is determined by both horizontal and vertical relationships between very different actors from the areas of public authorities, business, and civil society.

Comparative studies for a better understanding of institutional procedures and structures, the role of non-governmental actors (such as NGOs, NPOs, bottom-up initiatives, CSR in the economy), and institutional innovations count among the important aspects of this particular set of issues.

Questions regarding responsibility for climate protection – such as the extent to which it concerns households, the economy, NGOs, or government institutions – are also highly relevant.
Fulfilling climate protection responsibility sometimes requires that appropriate legal and financial framework conditions be established, which, in turn, constitute another important field of research.

3.5.2.5 Identifying Barriers and Enablers

Both transformation processes and progress in the area of climate policy, firstly, dependent on the removal of obstacles and, secondly, on the creation of enablers (whatever they are), as well as on an environment that not only promotes climate policy innovations but also accepts the possibility of their failure. Measures which may prove supportive of social transformation processes include, for instance, the establishment of new institutions as well as an appropriate adaptation of social incentives and tax and legal systems (on both national and international levels). In this context, the generation, availability, and dissemination of information are particularly important, as is the need to elicit and spread problem awareness.
The public sphere – i. e. especially the media and the education sector – are becoming increasingly relevant in terms of shaping the societal consensus and the public discourse on values.

3.5.2.6 Best Practice Analyses, Historic Transitions

Regardless of whether approaches towards transition and transformation prove successful or unsuccessful in times of comprehensive change, they always provide potential for learning.

Investigating important past transitions (such as the development of local supply and its reasons) from a historical perspective could also provide information on conditions for future transitions in respect of their necessity and sufficiency. It would also be beneficial to investigate the potential and limits of trans-national diffusion and learning processes. Science ought to closely observe and analyse current attempts at transforming society, and it should, moreover, attend to this process by scientific means. This includes the definition and implementation of appropriate indicators for changes and making thus identified changes accessible to scientific analysis.

3.5.2.7 Scientific Paradigm Shift

The scientific paradigm shift described in chapter 2.1 also raises a number of research questions.

These include the analysis of implicit scientific cultures that influence both climate research and the communication of scientific knowledge. It will be necessary to make such scientific cultures explicit, analyse their effectiveness, and challenge them if necessary. Inter- and transdisciplinary research (which have proven indispensable in the context of climate change and transformation research) is characterised by converging scientific cultures.

Among other things, new methods of addressing uncertainties contribute to consolidation in this area and at the same time constitute a research object of mutual interest.

3.5.3 Scenarios and Development Pathways

The above-mentioned measure should ultimately provide the basis for devising scenarios and development pathways which encompass different levels of detail and time scales and are made accessible to public discourse. However, the development of such scenarios and pathways, inter alia, still requires that both appropriate methods and models be assessed and further developed.

Methods of participatory scenario development could, for instance, provide an opportunity to involve decision makers in the process of determining and assessing changes that need to be made.

3.6 Inter- And Transdisciplinary Research Areas

The current chapter focuses on both cross-cutting and key issues in climate change research with regard to potential and necessary inter- and transdisciplinary co-operation.

3.6.1 Human-Environment Theory (as the Basis for Social Action in the 21st Century)

In the Anthropocene, the relationship between humanity and the environment reached a new dimension that has remained inadequately considered in existing theories on the relationship between man and the environment or, to put it another way, culture and nature. Social and economic structures significantly influence the decisions and / or actions of many individuals and determine the patterns of resource consumption that accelerate global climate change whose impacts, in turn, take effect at local, regional, and global levels.

Suitable problem-solving approaches must consider the fact that human beings are both the drivers of and driven by climate change. Moreover, they need to take into account the interactions between local and global transformation processes and must acknowledge the asynchronous relationship between decisions and actions and the effects they trigger.

The issue of interactions between anthropogenic and climate-related changes is also discussed in chapter 3.1.6. The goal of reducing CO2 emissions to such an extent that the average increase in global temperature can be limited to 1.5 to 2°C above pre-industrial levels is a major challenge that can only be achieved through substantial changes in resource consumption patterns and via large-scale technological mitigation measures. These will, however, have a profound impact on both the economy and society. In addition to a new conceptualisation of the interactions between humans and the natural environment or climate, it also requires the development of methods which enable for the incorporation of such interactions in modelling approaches. On the topic improvement of models see also chapter 3.1.5.

3.6.2. Sustainable Development – Indicators, Measured Values and Monitoring

Climate change mitigation strategies that aim at initiating transformation processes towards a climate-friendly economy and society should neither exclusively nor predominantly rely on measures determined by cost-benefit considerations that are, in turn, based on current rationality criteria/normative assumptions (such as operational or economic efficiency as defined by current institutional structures). Thus, prosperity and sustainable development indices play an important role in the transformation towards a more climate-friendly economy and society.

These can support such transformation processes by providing relevant information to create a broader basis for decision-making. Indices of the consumption of biophysical resources (such as land use or material and energy flow) and of the transfer of resource consumption and emissions between regions (such as carbon footprint or raw material equivalents) as well as new prosperity indices (such as the OECD Better Life Index or the Happiness Index and Beyond GDP mentioned in chap. 3.5.1.2) are particularly relevant in this context.

However, the question of whether simplification is more easily achieved by a headline index concept or by composite indices remains unanswered. Currently, systematic monitoring can only fall back on single indicators. There is still a need for research into the development of comprehensive and concise monitoring systems for sustainability.

3.6.3 Distillation of Climate Information

Scientists, practitioners and decision makers have access to a plethora of data on expected regional climate change. These include extrapolated observation series, global climate models, and various regional simulations.

There are still large uncertainties in these projections, and some data products are in part contradictory. It is thus essential to identify the relevant sources of uncertainties and distil reliable information from the given data. Model simulations must be linked to expert knowledge so as to realistically estimate uncertainties beyond ensemble spreads or create statements about variables that are difficult to model in the first place. The dialogue with data users is also addressed in chap. 3.1.6.

As mentioned there, an important issue is to assess the importance of climate change as compared to other influencing factors. Putting a focus on key topics provides the opportunity to develop best practice guidelines and use them as model examples for other regions in Europe or around the world. International exchange is also important, as it, in turn, facilitates learning from other regions. One key consideration is whether climate-related changes are relevant in relation to other socio-economic drivers.

3.6.4 Climate Change in Mountain Areas

Mountain ranges, and the Alps in particular, have pronounced microclimates and unique ecosystems. However, they are also living spaces, cultural spaces, leisure regions, economic areas, and resources.

Mountain research has a long tradition in Austria. Yet, since meteorological and climatological processes in mountain areas are particularly complex, there are still many research questions to be addressed. These include, for instance, inversions, flow and thermodynamic processes on all scales, and the emergence and manifestation of extreme weather events in particular.

As extreme habitats for plants, animals, and humans, mountains are particularly sensitive to changes. They are therefore also particularly suitable for early detection of climate change impact (mountain ecosystems as sentinels of change).

In this context, a robust understanding of the processes involved is highly important so as to avoid errors in identifying the causes of change.

Modelling against the backdrop of mountain climates is discussed in chapter 3.1.5.2.

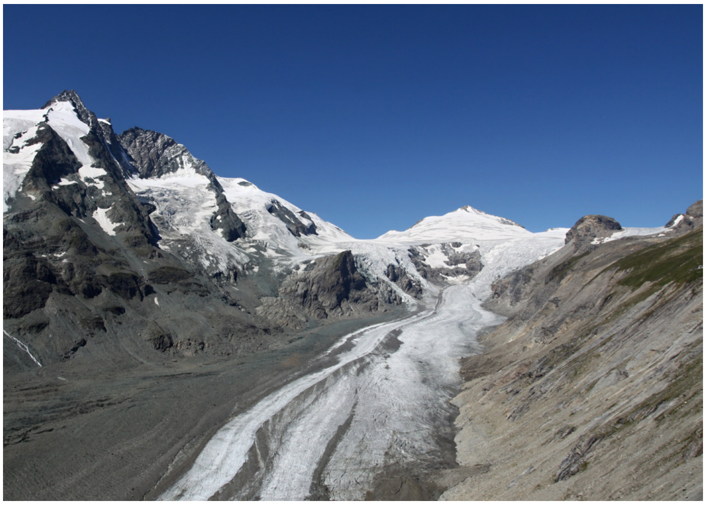

Fig. 16

Mountain areas are especially suitable for paleo-climate research, as they can also be regarded as diverse archives of earlier climates (many geological eras on surface, [ice] drill cores)

They, moreover, provide locations for observation and measurement stations that facilitate the collection of more widely representative data and make it possible to perform measurements even at cloud level.

Mountain areas are a challenge for remote sensing methods. This creates the opportunity for developing, in Austria, methods that can subsequently be applied on a global level. Questions concerning measurement frequency are also discussed in chap. 3.1.4.1, and the topic of long-term measurements in the context of mountain areas is addressed in chap. 4.1.2.

Small-scale climatic gradients (especially vertical), which are characteristic of mountainous areas, provide opportunities for analysing the long-term adaptation of organisms and ecosystems to the particular climate and for experimentally gaining understanding of climate change impacts.

Questions pertaining to monitoring within a mountain context are also discussed in chap. 3.2.2.1.

Interactions between the climate, alpine ecology, and socio-economic developments should be more closely examined than they have been thus far. In this context, resident communities must be considered both drivers of, and parties affected by, any changes. Appropriate communication, adaptation and research strategies could also be useful for any mountain region.

3.6.5 Climate- and Energy-Optimised Sustainable Cities

Cities are economic and living environments, places of intense social interaction, and cultural spaces. With increasing urbanisation, cities are gaining importance – also with regard to climate change: Firstly, they are major greenhouse gas emitters due to population, mobility, and economic as well as industrial activities.

Secondly, they also influence local climates in ways that exacerbate certain unpleasant characteristics of climate change.

However, at the same time, they are also a source of hope when it comes to emission reduction measures, especially with regard to technological progress which is hoped can be implemented more easily and quickly in cities (cf. smart city).

Finally, large amounts of data are collected in cities for a variety of purposes. This data could be used for climate research in the sense of crowd data. This, however, also increases the relevance of data privacy and protection.

Fig. 17

Open research questions concerning Austrian cities are diverse (see also chaps. 3.1.5 and 3.2.3.9) and relate to urban planning and architecture, the design of public spaces, and the development of legal tools for implementing mitigation and adaptation measures. Often, basic data (such as meteorological data) are lacking or are collected and stored according to criteria that reduce their usability in climate research (for instance in the health sector). However, many cities are also putting great effort into climate protection, which affords ample experiential knowledge on which to base scientific analysis.

While many technical issues regarding, for instance, thermal insulation, have already been well researched, there are still research needs in the field of the comprehensive assessment and optimisation of building materials' environmental and climate impacts. It is also essential to regard cities as integrated systems of nature, technology, economy, and human society whose essential functions and properties cannot be grasped and described by a single discipline.

3.6.6 Extreme Events

Extreme weather and climate events receive the most public attention of all climate phenomena. Their impacts affect a wide range of sectors and cause the highest costs (at least in the short term). Robust information on possible changes in the occurrence of extreme events is therefore of great interest for planners and decision-makers (see also chap. 3.1.2 for extreme events, and chap. 3.1.5 for models and simulations of extreme events).

Scientists are confronted with many enquiries in this respect. Have there been changes in the occurrence of extreme events? Can the severity of individual extreme events be traced back to climate change? How will characteristics of extreme events change in the future? (See also chap. 3.1.2.)

The frequently disastrous significance of extreme events, however, only unfolds within societal and ecological contexts.

Successful adaptation to extreme events thus also requires inter- and transdisciplinary research (including the humanities, social sciences, and economics) and must make use of local knowledge. Predictability and risk communication – both in principle and regarding specific incidents – are of particular interest for a successful adaptation to extreme events.

4. *Establishing Framework Conditions*

An important aim of climate researchers is to fulfil society's justified demand that science provides solutions to great global challenges, including climate change. This requires classical research, i.e. a striving towards knowledge and a better understanding of natural, man-made, and interacting systems and processes that must be scrutinised regardless of the subsequent findings' immediate usability.
Finding solutions to global challenges, moreover, requires further development of the current research system. Such a development encompasses, inter alia, a conceptual expansion of the notion defining research as informed by the natural sciences and the development of both appropriate quality indicators and new scientific communication and publication cultures. Many of these changes can be initiated and implemented by science itself, while others require improved underlying conditions.

4.1 *Improving Scientific Tools*

4.1.1 Consistent Reference Periods and-Scenarios (Comparability)

In both IPCC AR5 and APCC AAR14, numerous important statements are devalued by the fact that they apply to different time periods, which makes a comparison or connection with other statements difficult or even impossible.
However, consistent reference periods are a requirement for the proper comparison and interconnection of scientific findings, due to the complexity of both climate change-related processes and climate change impacts.

For the CCCA to define standardised reference periods is recommended.
Scenario-based studies should likewise define reference scenarios that can be applied for comparative purposes as appropriate.

4.1.2 Long-term Measurements

Climate change research relies on long-term measurement series. This means that
a) existing long-term measurement series must not be discontinued in favour of other, currently more interesting projects;
b) selected discontinued measurement series (such as meteorological measurements in the urban area of Vienna and in high mountain regions) should be resumed; and
c) new measurement sites should be selected, and new observational variables defined; they should take into account the long-term character of the measurements and ought to be imbedded into an institutional context (of, for instance, the Zentralanstalt für Meteorologie und Geodynamik, the Environment Agency Austria, or Statistics Austria; universities are usually not ideal environments).
A systematic analysis of the data situation in Austria would be desirable, as would subsequent proposals for both additions to and changes regarding this situation which take into account the above aspects (cf. points a to c). The funds for implementing these recommendations (as well as potential further ones resulting from them) must be provided. However, when planning new research projects that include data collection, it must be determined in advance whether the respective research

question could not be investigated using the existing network. It goes without saying that even an optimised network will always require some adaptation.

4.1.3 Digitalisation

Due to climate research operating in the context of long-term observations, pre-digital data can be of high research value. This includes meteorological, hydrological, glaciological and vegetation ecology-related data, data on yields and damages in agriculture and forestry, and insurance data.

Funds for the systematic location, acquisition, and digitisation of such data records and for making them accessible (for example through the CCCA climate data centre) are necessary and would represent good value.

4.1.4 Consistent Databases

Consistent collection of loss data and the homogenisation of existing data records would significantly improve analysis options.

Trans-national data records are necessary for conducting comprehensive analyses of the Austrian federal territory. Thus, Austria should conduct generous data exchange with its neighbouring countries, and relevant data should also be accessible via Austrian databases.

Fig. 18

4.1.5 Literature database and archive

Some climate research is only published in so-called grey literature. So as to make the best possible use of and adequately assess this kind of literature, it must be made known and accessible.

The climate research community should make it their concern to enter their own publications into the CCCA literature database and deposit or link the full texts (preferably in a digital format).

4.1.6 Open Data Access

In the context of climate change issues, it is essential to have access to as much data as possible. Open data access at all levels is therefore important. This involves, first of all, the provision of metadata via appropriate databases, increasingly required in publicly funded research. Open access also ensures that a research topic can be carried forward in detail even if the original researcher is no longer active in that research area. It is, moreover, advisable to publish in scientific journals with a strong open-access policy. Thus, data will become accessible to a wide readership, so stimulating scientific discourse beyond classic peer review processes. Open access publications are sometimes rather costly, which must already be taken into account during application for funding by both applicants and funding bodies or institutions.

4.2 Expanding The Range Of Scientific Products

4.2.1 Assessment Reports (Assessments)

There is a need for gathering existing knowledge and utilising it for stakeholders and society.

In continuation of the Austrian Assessment Report on Climate Change 2014 (AAR14), assessments on sub-areas and specific issues (such as human health, tourism, spatial planning, or bioeconomy) are to be drawn up and submitted. At an appropriate interval, also an updated edition of the AAR14 is to be produced in collaboration with the interested scientific community.

4.2.2 Prompt Provision of Information with Relevance

Both government and private actors are sometimes forced to take action or desire to do so. Yet, they often do not have, or take, the time to await further scientific research results. However, since existing knowledge often already provides a good basis for relevant decisions, it is important for researchers to carefully interpret and evaluate this knowledge in cooperation with relevant experts and thus make it usable. Clarification regarding the potential of existing scientific information as well as its limitations is essential.

4.3. Measures To Be Taken In Research And Science Policies

4.3.1 Increasing Project Funds for Interdisciplinary Projects

Research policy must provide higher project funds for interdisciplinary projects (including integration studies) in order to facilitate the integration of all relevant scientific disciplines and ensure that more comprehensive research questions can be appropriately investigated and more extensive communication costs be covered.

4.3.2 Competitiveness and Promotion of Young Reseachers

Excellent and socially responsible research requires that young researchers be given the opportunity to concentrate on (preferably no more than) one specific project and that they be afforded medium-term employment and research prospects (about two years for postdoctoral researchers and at least three years for Ph.D. students). Project lifetimes of these magnitudes relieve researchers of the additional burden of having to write proposals and reports for short-term projects. In addition, they are more attractive to outstanding candidates who need to be recruited from the highly competitive international job market.

4.3.3. Incentives for Climate-friendly Research

Application requirements for research funding should include a statement on appropriate measures for the climate-friendly design of the proposed research. Funding bodies and institutions as well as clients ought to acknowledge additional costs for climate-friendly behaviour (such as train journeys instead of flights) and CO2 compensations (for example for flights).
Research institutions should increase their efforts towards establishing internet-based, virtual conference spaces.

4.3.4 Adapting Legal Frameworks to new Challenges faced in Science

In order to increase the social engagement of researchers, services provided to society (such as citizen science, policy advice, or media work) must be contributory to a career in science.
This includes extending the evaluation criterion of "Scientific Excellence" in all relevant research environments by the (in fact already) statutory "Societal Impact" parameter.

5. Current State of Climate Research in Austria

5.1. Research Networks

The Austrian climate research landscape features research networks at national, and regional or local levels. The Climate Change Centre Austria (CCCA) and its 28 members (universities and non-university research institutions) have tasked themselves with fostering climate research in Austria, promoting young scientists, supporting knowledge transfer, offering advice to both policy-makers and society, and advancing the international visibility of, as well as networking opportunities for, Austrian climate research (for instance via participation in research programmes and representation in committees and panels).

Against this backdrop, the CCCA considers itself a point of contact between researchers, policy-makers, the media, and the public in respect of all climate research related issues in Austria. The CCCA also aims to reinforce trust among its members and stakeholders and at helping overcome language barriers, thus promoting a sustainable climate dialogue in Austria.

5.2 Research Competence and Research Services; Actors (Competence Map)

Both estimates and the numbers of participants in internal workshops at CCCA member organisations suggest that there are about three to four hundred scientists working in climate research in Austria. Their findings are taken up in discussions on climate change related and geographical issues as well as research policy.
The results of national research are included in the development and implementation of national, regional, local, organisational, and individual climate change mitigation and adaptation strategies.
Besides climate research that is mostly received on a national level, contributions from internationally- and mainly Europe-oriented research activities in Austria have also been integrated into the work of international consortia such as the IPCC, the Global Energy Assessment, the Global Biodiversity Outlook, the Global Mountain Biodiversity Assessment (GMBA), and the LTSER Network (Long-Term Socio-economic and Ecosystem Research). Austrian climate researchers have been contributing to the fields of both basic and applied research, and the first steps have been taken towards participation in transformation research.

The CCCA has developed a 'competence map' that ought to provide an easily-accessible overview of all climate researchers in Austria.
It maps the particular fields in which individual researcher are active, outlines their specific research interests, and summarises the research activities in which they have been involved.

The competence map thus provides useful information for establishing research consortia and functions as a directory for private individuals and business and policy representatives who wish to make enquiries.
The map is regularly updated and is being further developed so as to present the most comprehensive survey to date of the Austrian climate change research landscape. The consolidation of local and regional networks – which, in Austria, exist in Vienna, Graz, and Innsbruck – creates significant added value for Austrian climate research.

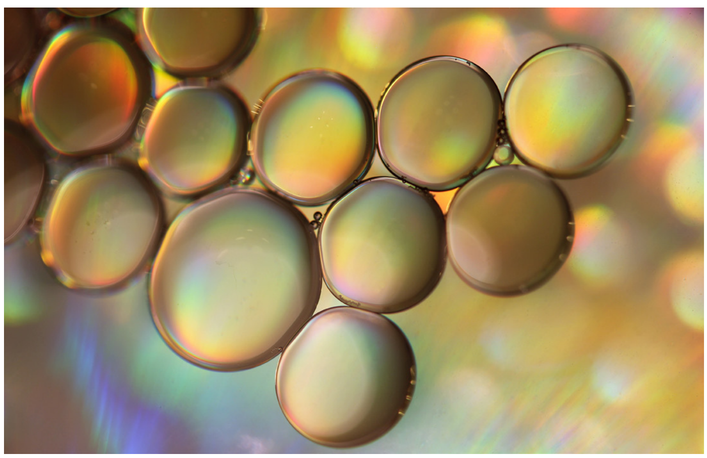

Fig. 19

This is also reflected by the fact that the CCCA and the BMWFW (Austrian Federal Ministry of Science, Research and Economy) have developed an important strategic partnership in the context of the Joint Programming Initiative "Connecting Climate Knowledge for Europe" (JPI Climate), especially regarding the implementation of the JPI's strategic research agenda at both national and international levels. This partnership also includes a collaboration in setting agendas for the European Commission's Framework Programmes (such as Horizon 2020) and forms the basis for co-operation within the BMWFW's "Responsible Science" programme on climate research.

5.3 Austrian Assessment Report 2014 (AAR14)

The project of initiating and drawing up an Austrian Assessment Report on Climate Change, which was supported by the Austrian Panel on Climate Change (APCC) initiative and the CCCA, demonstrates the successful performance of the Austrian climate research network. Constituting the first Assessment Report for an individual country, the Austrian Assessment Report 2014 (AAR14) has attracted great national and international attention and made a positive contribution to raising climate change awareness in the public, policy, and economic sectors. The report provides an excellent, annotated summary of Austria-related climate change knowledge and thus serves as an important basis for political and economic decisions-making processes.

5.4 Research Funding

Climate research is characterised by a wide range of national and international funding structures.
In Austria, the funding instruments of the Austrian Science Fund (FWF) allow scientists to submit proposals for projects that correspond to their particular research interests and are not restricted to preconceived research agendas. In addition, programmes such as the Climate and Energy Fund's Austrian Climate Research Program (ACRP) offer an opportunity for conducting applied research that is coordinated with national research priorities and their respective policy relevance. There is, however, still a strong need for promoting transformation research.

Due to its inter- and transdisciplinary character, it is very difficult to categorise transformation research in terms of the FWF's funding structure, and with regard to the requirements of the ACRP programme, transformation research often lacks a sufficiently direct relationship to explicitly climate-related issues. A 2013 call issued by the JPI Climate programme for transformation research proposals was, in fact, the first attempt at promoting this.

In the context of the development of the European Research Area (ERA), European Joint Programming Initiatives (JPIs) are becoming increasingly important for research funding and supplement the European Framework Programmes (such as Horizon 2020). Some Joint Programming Initiatives – such as JPI Climate, JPI FACCE or JPI URBAN EUROPE – are also closely related to climate research.

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The Science Plan Working Group, a strategic working group set up by the Climate Change Centre Austria, was responsible for finalising the Science Plan.

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Georg Kaser was the leading figure in laying the foundation for the Science Plan. Within three thematic subgroups, the following individual developed the initial concept for and contents of the Science Plan:

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In 2015, Helga Kromp-Kolb and Hans Stötter merged and restructured the documents contributed by the individual subgroups to produce a consolidated draft. The current version of Science Plan (March 2017) is based on this draft.

Participation of the Austrian Climate Research Community

To keep contributions to the Science Plan as broad and open as possible, various forms of participation were offered. Thanks are due to the approximately 100 scientists from 20 Austrian research institutions who contributed to preparing the document in workshops, working group meetings and by way of the commenting process. The latter alone, generated approximately 500 comments from the research community, which were integrated into the present Science Plan version by the working group, following a quality-controlled process in accordance with the IPCC.

Co-ordination

The CCCA staff accompanied the drafting process of the Science Plan in organisational terms. Julia Kolar and Ingeborg Schwarzl oversaw the general co-ordination, Heide Spitzer was responsible for the layout, and Stefan Ropac managed public relations matter. Among former CCCA staff, Sebastian Helgenberger is to be mentioned for his participation in the Science Plan. Thanks for proofreading and editing go to Matej Kundracik.

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Fig. 3: Measurements: Wegener Center, University of Graz
Fig. 4: Levels of Theory and Methodology: APCC_B2K5_Nat Forest Regeneration: Natural Forest Regeneration with Pine (Pinus cembra) and Larch (Larix decidua) in the Area of the Subalpine Tree Line on Former Pastures in the Municipality of Sölden (Ötztal) at approx. 2,200 m above sea level in 2005. Image: D. Stöhr.
Source: Baumgarten, A., C. Geitner, H.P. Haslmayr and S. Zechmeister-Boltenstern, 2014: Der Einfluss des Klimawandels auf die Pedosphäre. In: Österreichischer Sachstandsbericht Klimawandel 2014 (AAR14). Austrian Panel on Climate Change (APCC), Verlag der Österreichischen Akademie der Wissenschaften, Wien, Österreich, pp. 601–640.

Fig. 5: Data, Measurements: pixabay.com_rschaller98
Fig. 6: Impacts of Extreme Events (variability): APCC_B2K4_Mudslides: Land- and Mudslides Caused by a Stationary Thunderstorm with > 130 mm Precipitation in 3 Hours in the Kleinsölk Valley in 2010. Image: Markus Mayerl, Forest Engineering Service in Torrent and Avalanche Control, Regional Headquarters for Ennstal and Salzatal
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Fig. 7: Climate Change Impacts on Human Health and the Social Fabric: APCC_B2K6_ Asiat. Tigermücke: Asian Tiger Mosquito (Aedes (Stegomyia) albopictus). Image: R. Pospischil Source: König, M., W. Loibl, R. Steiger, H. Aspöck, B. Bednar-Friedl, K.M. Brunner, W. Haas, K.M. Höferl, M. Huttenlau, J. Walochnik and U. Weisz, 2014: Der Einfluss des Klimawandels auf die Anthroposphäre. In: Österreichischer Sachstandsbericht Klimawandel 2014 (AAR14). Austrian Panel on Climate Change (APCC), Verlag der Österreichischen Akademie der Wissenschaften, Wien, Österreich, pp. 641–704.
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Responsible for the Content
The Climate Change Centre Austria (CCCA) is responsible for the content. Despite extensive participation processes, the content does not necessarily reflect the opinion of all CCCA members.

The process of developing a Science Plan dates to the beginnings of the CCCA. It was initiated by the “Strategic Development of the Climate Change Centre Austria” project of the former Ministry of Science and Research (BMWF). Besides the relevant funding, it was the extensive in-house contribution of the CCCA community which made the Science Plan possible. Further information on the development of the Science Plan and on the related participation process are available on the CCCA website at www.ccca.ac.at.

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