Deutsches Klima Konsortium

Future Prospects for Climate Research 2015 to 2025

Position Paper

In 2013 and 2014, at the invitation of the Deutsche Klima-Konsortium (the German Climate Consortium, abbreviated to "DKK"), scientists from all leading German climate research institutions met with social and political experts at a series of workshops to come to an understanding about future perspectives on climate research.

This position paper describes the three topics that were dealt with in the working groups. Further research into climate systems is the first topic, as there are still significant gaps in our knowledge despite enormous progress. The second topic deals with climate risks. These risks, which arise as a consequence of climate change, must be identified more accurately, must be better characterised and – where possible – must be quantified in terms of probability and level of damage caused. The third topic covers the various roles adopted by climate research in a democratic society and the opportunities to contribute to crucial issues of societal transformation.

The DKK's and the participants' objective was to identify the scientifically promising and socially relevant issues within the specified topics. With this paper, the DKK aims to shape the emerging structural change in climate research and to encourage reflection within the scientific community and beyond.

Contents

Preamble

Anthropogenic climate change has been in the international spotlight for many years, not least because the risks of unchecked global warming are recognised as incalculable. That the Earth's climate is changing and that humans are the main cause is not disputed scientifically and has been emphasized once again in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, the IPCC[1].

That the Earth's climate is changing and that humans are the main cause is not disputed scientifically.

The discovery of human influence on the climate is based on years of intensive research and has been widely accepted within society following extensive debate both inside and outside academia. Scholars in Germany have made a significant contribution to both research and debate.

This DKK position paper highlights future perspectives in which the successful work conducted to date by German climate researchers can be taken forward over the next ten years.

Continuing with scientific achievements – providing policy-relevant knowledge

German climate research and climate impact research is very well positioned both nationally and internationally. For many years now scientists from Germany have played a leading role in the IPCC Assessment Reports. They are active in the relevant international committees such as WCRP, IGBP, Future Earth[2] and others. At a national level, three Clusters of Excellence dedicated to climate science have received funding as part of the federal and state-level Excellence Initiative, while climate scientists have played a major role in the development and implementation of research programmes at an international level. The close coordination of regular and third-party funding activities along with collaborative research conducted by universities, Helmholtz Centres, Max Planck and Leibniz Institutes as well as various governmental research institutions have proven their worth. Both now and in the future we seek to play a key role in German research and to take a leading position in international climate research and climate impact research.

Despite enormous achievements, there are still significant gaps in our knowledge of important processes in the climate system and its modes of response to human influence. This is particularly true of regional and local impacts, which may vary significantly. One example is sea level rise, which has developed in very varied ways on different coastlines over the course of recent decades and will continue to do so in the foreseeable future. Therefore research on the climate system continues to be a topic of crucial importance.

Despite enormous achievements, there are still significant gaps in our knowledge.

At the same time an increasingly important issue is the extent to which climate research is capable of providing knowledge relevant for practice in response to climate change. Does science explore the questions that concern politics, businesses and civil society? And also, are scientists asking the questions that society should be asking itself? Does the scientific community provide answers that will be heard in the non-scientific world? Can scientists participate actively in the debate on the key issues of societal transformation without leaving themselves open to accusations of abandoning scientific integrity?

The challenge of climate change

Climate change is very hard to comprehend using our common patterns of perception and is often underestimated by politicians and the public.

Climatic changes are complex, they can extend over long periods of time, and they can affect some regions much more intensely than others. They may interact with other adverse developments in a society, such as land use, and they may reveal drastic effects only after decades or even centuries have passed. This complexity makes climate change very hard to comprehend through our common patterns of perception, and climate change, much like other systemic risks, is often underestimated by politicians and the public.

Dealing with climate change poses a threefold challenge to science:

1. Although the underlying principles of the climate system are understood scientifically, problems arise when it comes to understanding the details. Projections[3] based on climate models, for example, are still beset by uncertainties. The aim must be to reduce these uncertainties or at least to better characterise their nature and extent, as it is impossible to resolve them completely.

2. Secondly, climate impacts – that is, the effects of climatic changes on nature and society – have been difficult to estimate up to now. This includes on the one hand the effects of climate change itself and what impacts it will actually unleash on civilisation. On the other hand we do not know which kind of societies will be affected by these changes. Because, parallel to climate change, ongoing political, economic, technological and social changes are taking place.

3. Finally, there are questions regarding the role climate research can and should play in dealing with climate change in a democratically constituted society. This involves questions about how climate researchers view their own work, about new fields of social science research and about interdisciplinary and transdisciplinary research formats as well as challenges of providing knowledge relevant for practice in response to climate change.

Three key areas of research relevant to society

In light of these challenges, the German Climate Consortium has identified three key areas of research which will be relevant over the next ten years:

1) deepening the understanding of the climate system,
2) assessing and dealing with climate risks and
3) identifying the different roles of climate research in democratic societies.

This threefold division derives from work carried out in a series of workshops run by the DKK along with other experts – including representatives from all leading German climate research institutes – in Potsdam during 2013 and 2014. While we do not claim to have developed an all-encompassing agenda, we do believe we have identified and fleshed out the key questions in the areas specified.

I "Understanding climate" encompasses the topic of "Reducing uncertainty in climate projections" and is thus about seeking to minimise the errors in climate models and improving our understanding of climate processes. Model-based projections, which contribute significantly to estimating climate impacts, can only be as good as the scientific knowledge of the climate system. To progress in this area we need to continue to evaluate data jointly and to further develop observation methods and models. The aim is to become capable of determining climatic changes more precisely at a global level and – a particularly challenging task – to break the models down to the regional level more accurately (so-called 'downscaling'). This would make it possible, for example, to predict the frequency and intensity of tropical cyclones more precisely in the future. Climate adaptation strategies which relate largely to local and regional circumstances require this localised climate information. In the medium term therefore, it would be useful to have a national modelling strategy.

A seamless forecasting system would enable proactive planning.

Five other topics that were proposed relate to the understanding of abrupt climate changes, changes to the water cycle in a warmer world, the correlation between air quality and climate change, and biogeochemical cycles and their interaction with the physical climate system. Finally "Understanding climate" comprises the extension of weather forecasts into climate forecasts on a timescale of up to two or three months, the long-term aim being to develop a seamless forecasting system. This would enable proactive planning to ensure the availability of food, water and energy as well as to manage extreme weather events.

II "Dealing with climate risks" focuses on the issue of assessing and managing current and future climate impacts. Climate impacts are potential climate risks about whose probability of occurrence and potential for damage we know very little. In this complex field, improved knowledge about the probability, the distribution and the potential damage caused by climate risks can be achieved through a process of integrated research[4]. Politics, business and civil society need adequately verified knowledge in order to adapt to climatic changes that cannot be avoided and, at the same time, to limit climate change by means of far-reaching social and economic transformation – the catchword here being 'low-carbon society'. Whatever decisions are made regarding measures to mitigate climate change (climate protection) and to adapt to it[5], they will entail advantages and economic opportunities for some parts of society and disadvantages for other groups, as well as costs to society as a whole. A risk management system based on the best climate science information available to enable adequate decisions is still lacking. If this were otherwise, it would reduce the costs of climate protection and adaptation. In cases where it is not possible to determine probabilities and degrees of damage with sufficient certainty despite intensive research, the quantification of climate risks comes up against its limits. The task of research in such cases is to identify these constraints more precisely and perhaps to move towards the precautionary principle commonly recognised in the area of environmental law, which recommends measures even if risks have not (yet) been adequately determined.

A risk management system based on the best climate science information available is still lacking.

III "Climate research in democratic societies" deals in part with the ways climate researchers view their own work and respond to the growing demand to provide politically relevant knowledge. The debate on climate change is shifting from a predominant focus on biophysical processes to societal processes and concerns interacting with the climate and environment. At the same time climate policy is acknowledged as being embedded in many other areas and must be seen as just one, albeit important, component of the overall system. Climate researchers are therefore called upon to cooperate in solving pressing questions of future concern, yet without compromising their scientific integrity. This gives rise to a host of new tasks to be tackled by basic social scientific research and the need for accompanying research in the context of co-design, co-production and transdisciplinarity. To provide policy relevant knowledge, climate researchers are called upon to cooperate with a variety of state and non-state actors.

New research questions emerge from the perspective of society and the internal logic of democratic processes.

In detail: First, the view is directed "inwards" to reflect upon the role of climate researchers in the context of the way climate change is dealt with in society. Second, it will be shown that the spectrum of issues and scientific disciplines has become broader and that climate research is undergoing structural change. The social sciences are assuming greater importance, requiring the development of both basic research and new interdisciplinary and transdisciplinary approaches. This in turn results in new research questions which start out from the perspective of society and the internal logic of democratic processes rather than climate change and which offer points of reference for a climate research programme underpinned by social science.

The third part addresses the information needs of politics, businesses and civil society and explores challenges and opportunities of providing scientific knowledge in a useful and relevant way. This means for instance to systematically review the existing landscape of policy relevant science and to assess their standards and quality.

Our intention with this paper is to help shape the structural change that is imminent in climate research and to encourage well-founded reflection upon future challenges.

On the one hand we demonstrate where climate research can contribute to address politically relevant questions. On the other hand, we seek to address the relevant authorities and institutions at federal and individual state level. Eventually, we as the German Climate Consortium, would like to enter into a dialogue with the scientific community about future issues and possibilities of tackling the problems.

In terms of the way the DKK views its own role, we also deem it important to make the interested public aware of the work and potential of climate research. Particularly because complex solutions are required which cannot be conjured by science alone, and precisely because the future will include value-based decisions which science too must face as one actor among many in a democratic society, dialogue with citizens and joint problem solving will be decisive.

The challenges of understanding our Earth's climate and of finding effective and legitimate solutions require meaningful ways of working together – the scientific community alongside with a broad range of state and non-state actors from the regional to national and international level.

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I Understanding climate

In recent decades, German climate research has contributed significantly to the understanding of the climate system and made its results available to the international community. As a result, German scientists have contributed in a leading role to the reports of the Intergovernmental Panel on Climate Change (IPCC), which summarise and assess knowledge on climate change at intervals of several years. In addition, they have helped to shape crucial research programmes and have established three Clusters of Excellence in climate research at the national level.

The gaps in knowledge relate both to the understanding of individual processes and to the interactions between the individual climate system components.

While the underlying principles of the climate system are understood scientifically, there remain significant gaps in our understanding of the climate system. These relate both to the understanding of individual processes and to the interactions between the individual climate system components.[6] As a result, the dynamics and predictability of natural fluctuations in climate across a broad spectrum of timescales, from a few weeks to decades and longer, have not been conclusively resolved. This also applies to the wide field of abrupt climate changes and to climate extremes. There are also major gaps in our knowledge of biogeochemical cycles and their interaction with the physical climate system.

Six areas will be outlined below in which German climate research can achieve important breakthroughs in the coming years, thanks to its research expertise. These include both questions which have long been and will continue to be the focus of national climate research in the future as well as new areas. The six proposed areas are closely integrated into the relevant international programmes.

Generally, to the benefit of all research activities, the observation systems and Earth system models should be further developed and refined or entirely new approaches should be put to the test.

The strengths of German climate research lie in the close cooperation of institutional and externally-funded activities, close cooperation between universities, Helmholtz Centres, Max Planck and Leibniz Institutes as well as various departmental research institutions, and, in addition, in the successful cooperation between theoretical, observational and modelling groups. This proven, well-established strategy should be continued in the future.

1.Determination and reduction of uncertainties in climate forecasts and climate projections

Uncertainties in the projections of the future climate can be traced back to three factors:

1. model errors,
2. internal variability of the climate and
3. lack of knowledge about the future emissions of greenhouse gases such as carbon dioxide (CO_2), and other climate relevant substances.

In general, the models should pass as many tests as possible so as to increase their reliability. Simulations of the past climate, among other things, play an important role in this. The extent to which projections about the future climate can be improved by a realistic simulation of the past climate, particularly for long-term projections up to the end of the century, or even to the end of the millennium, remains unclear. But a detailed comparison of simulated processes in the various climate system components with observations, reconstructions and experimental results is indispensable to increase the quality of the simulation and the understanding of the process. This requires, in particular, the continuation and, where necessary, expansion of the climate observation system.

The reduction of systematic model errors is a cross-cutting issue and requires an overarching strategy. For the foreseeable future, the concept of using a range of models will continue to be applied, i.e. the various questions require resolutions and models tailored to the problem, such as in the regionalisation context. As a general rule, a higher spatial resolution model is desirable. Therefore, a greater range of the simulations will be shifted from the parameterised[7] into the explicitly-represented regime, which often (but not automatically) increases the quality of the simulations. This particularly applies to the field of ocean-atmosphere-sea ice interactions, which are so important for the European climate.

In addition, the dynamic integration of additional components of the Earth system, particularly the cryosphere[8] and biosphere[9], still represent a major challenge as model resolution increases. High-resolution global climate simulations at a range of a few tens of kilometres have to date not been attempted comprehensively and strategically in Germany. There are hardly any pilot studies and none of the existing projects is technically prepared for the coming generations of high-performance computers. The demands on IT infrastructure will increase. For example, a halving of the grid point spacing means an approximate ten-fold increase in the necessary super-computer capacity.

High-resolution global climate simulations at a range of a few tens of kilometres have to date not been attempted comprehensively and strategically in Germany.

In the medium term, a national modelling strategy is required, aiming systematically to achieve the highest-possible spatial resolution for climate projections to the end of the 21st century. In this regard, the optimisation and adaptation of the model codes to fast-changing computer architectures is essential. For qualitative advances, an improved process understanding is also required, which necessitates close cooperation between theoretical modelling and measuring research groups (see sections 4, 5 and 6 in this chapter).

Climate predictability, however, is fundamentally limited, and it remains the task of climate research to better define these limits.

Climate predictability, however, is fundamentally limited, and it remains the task of climate research to better define these limits. One of the reasons for this limitation lies in internal climate variability, which arises from the chaotic dynamics of climate and, along with fluctuations caused by natural external forcing (e.g. sun and volcanoes[10]), superimposes anthropogenic climate change. Ocean processes play a particularly important role in this. Changes in the ocean currents cause regional differences in sea level, which superimpose global sea level rise. An important and necessary element to understanding and predicting the internal variability is therefore a global ocean observation system. But processes in the cryosphere and on land also play an important role in internal variability. To date, Germany has delivered significant contributions in the area of climate variability and a continuation of these activities as well as the development of innovative measurement methods is indicated. Consideration of internal variability requires suitable methods for initialising climate models, as well as ensemble simulations, i.e. multiple simulations (realisations) with identical forcing, but different initial conditions. A particular challenge here is that only one observed realisation for the model evaluation exists (see also section 2).

And finally, scientists in Germany have extensive experience in the elaboration of greenhouse gas budgets and scenarios (see section 6). Natural sources and sinks[11] of greenhouse gases will change over time as a result of climate change, which will in turn affect the evolution of the climate. Both process understanding and modelling in regard to biogeochemistry require intensive research.

2. Extending the weather forecast and linking it to the subseasonal climate forecast

Following the ground-breaking work of Edward Lorenz in the 1960s on the chaotic behaviour of the atmosphere, it has long been assumed that useful weather forecasts more than two weeks into the future were impossible.

In the 1980s, it emerged that the climate system allowed predictability on seasonal timescales of a few months. One example is the El Niño/Southern Oscillation Phenomenon (ENSO[12]) in the tropical Pacific, with its global effects. German research made important contributions in this area.

For a long time, however, there have been no robust forecasts for the subseasonal range, which lies between classic weather forecasting and seasonal climate prediction. The first operational subseasonal forecasting systems have now been in existence for a number of years and have produced surprisingly good results even in the extratropics. In contrast to seasonal forecasts, which are primarily dependent on the conditions of the oceans and sea ice, the current condition of all of the atmospheric drivers – including land parameters such as the distribution of snow and ice cover – play a crucial role in the field of subseasonal forecasting from about 14 to 60 days. In addition to the quality of the simulations, the most exact knowledge possible about the external boundary conditions and their representation in the models is vital. This requires, among other things, suitable measurements of land parameters such as soil moisture.

Subseasonal forecasts provide meaningful contributions to process understanding and, in particular as part of the forecast chain, are of crucial importance for the end user, for example for the proactive planning of food, water and energy availability and for dealing with extreme weather-related events.

Subseasonal forecasts provide meaningful contributions for the end user and enable proactive planning.

Research in the area of subseasonal forecasting has become the focus of international programmes. Thus, for example, the World Weather Research Programme (WWRP) has initiated the Subseasonal to Seasonal (S2S) Prediction Project, together with the World Climate Research Programme (WCRP). This project represents a significant contribution to the development of a virtually seamless prediction system.

The success of subseasonal forecasting ultimately depends on the better representation of atmospheric phenomena such as oscillations in the tropics with periods of one to two months, the coupling with the land-ocean-cryosphere and the integration of stratospheric processes into the prediction models. Overall, however, we currently know very little about the conditions for good quality forecasts on these timescales of a few weeks. This represents one of the significant research tasks.

3. Abrupt climate changes

Abrupt climate changes pose particular challenges to both ecosystems and human society.

Reconstructions of past climates demonstrate a range of abrupt climate changes. In particular, the climate during the last Ice Age featured significant variability, with rapid climate changes within just a few decades. These changes were often associated with swift reorganisations of ocean circulation. However, their causes have not been conclusively explained. Another example is the extremely rapid rise in sea level (melt water pulses) – with increases of several metres per century – during the transition from the last Ice Age to the current Warm Period. Strong volcanic eruptions have repeatedly led to climate extremes in the recent past, resulting in social upheaval. The explosive volcanic eruptions are not necessarily predictable, but their consequences can in theory be calculated.

The significant research questions revolve around the identification and more precise understanding of the dynamics of such tipping points and of climate impacts, as well as the risk of exceeding critical thresholds.

Are abrupt climatic changes to be expected as a result of anthropogenic climate change? A range of large-scale subcomponents of the climate system could, as theoretical reasoning suggests, "tip" as a result of human activity – one example would be the irreversible melting of the Greenland ice sheet, with an increase in sea levels of seven metres in the global average. Or they could display pronounced non-linear behaviour – such as the frequent disturbances in the Indian Monsoon. But what are the critical thresholds that, when exceeded, will trigger irreversible processes or regime change? The vital future research questions revolve around the identification and more precise understanding of the dynamics of such tipping points and of climate impacts as well as the risk of exceeding critical thresholds due to anthropogenic climate change (see also Chapter II, "Dealing with climate risks").

In this regard, climate information from the past, both from marine and temporally high-resolution terrestrial archives, plays an important role.

Among the most important research topics are:

- ice sheet instabilities resulting in rapid increases in sea levels,
- possible instabilities in ocean circulation (e.g. a collapse of the Atlantic circulation) or the atmospheric circulation (regime change),
- the stability of forest and savannah ecosystems and coral reefs,
- the release of greenhouse gases due to the thawing of permafrost on land,
- the release of marine methane hydrates (so-called frozen methane)
- excessive acidification of the world's oceans due to the oceanic uptake of CO_2 with unforeseeable consequences for the marine ecosystem[13]

The methods comprise modelling, instrumental measurements and obtaining proxy data[14]. Among other things, the main issue is to continuously improve the relevant models of Earth system components (atmosphere, ocean, ice, land, ecosystems, material cycles). This requires improvement in the explicit representation and parameterisation of key processes. For example, to be able to simulate rapid rises in sea levels, inland ice modelling requires integrating the dynamics of the transition line from inland ice to floating shelf ice, subglacial hydrology, the interplay between the ocean and shelf ice and the mathematical numerical formulation of the interaction of a range of scales. And finally, there is the question of how ecosystems will react to multiple stress factors and how they will interact with the climate.

4. Water cycle in a warmer world

The water cycle is one of the most important components of the climate system, determining, among other things, the distribution of clouds and precipitation on Earth.

It is certain that anthropogenic climate change has already affected the water cycle and that this effect will increase. Water appears in the atmosphere in all three phases: water vapour, liquid water and ice. Water vapour is an important greenhouse gas and contributes to up to two-thirds of the natural greenhouse effect. Every warming by carbon dioxide (CO_2), methane (CH_4) or other greenhouse gases leads inevitably to more water vapour in the atmosphere, thereby amplifying the anthropogenic greenhouse effect. An important question in this regard relates to changes in extreme weather such as heavy precipitation and droughts. The available measurement series are still too short to understand the connection to global temperature changes in detail. Here, terrestrial climate archives offer unique opportunities to reconstruct flood events with seasonal resolution over millennia.

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Water is not only stored and transported in the atmosphere, it also has a vital influence on the energy balance of the Earth due to its particularly strong absorption of infrared radiation and its phase transitions. It therefore plays a critical role in determining the strength and pattern of atmospheric circulation and thus the resulting climate changes, particularly at the regional level.

Despite the significance of the water cycle for weather events, for regional climate, extreme weather, air quality and biological activities, there is still a significant lack of knowledge on the role of water in the climate system. Climate sensitivity[15], too, depends quite critically on the understanding of the water cycle and its underlying feedbacks. Cloud processes and the interaction with aerosols play an important role in this regard.

In addition, there is insufficient knowledge about water vapour variability in the boundary layer to the stratosphere (tropopause) and about the properties of the ice clouds in the upper atmosphere, as well as about precipitation and evaporation over the ocean.

To better understand and model the exchange of water between soil, vegetation and the atmosphere, an adequate representation of its role in soils and plants is required. Due to the scales to be taken into account – from the pore-size distribution of soils to global changes in land use – this is a major challenge for climate modelling. This is where closer integration of weather forecasting and climate models, as well as an improved database, takes on particular importance.

The development of research infrastructures, measurement and observation technologies must focus on the aforementioned key processes.

Water affects almost every aspect of the climate. To better understand the water cycle and future changes, the development of research infrastructures as well as measurement and observation technologies must focus on the aforementioned key processes. This means, in particular, combining observations and models, developing common tools for the optimal utilisation of existing and future observations (standardisation, homogenisation) and integrating what are often separate investigations into water vapour, clouds and precipitation. This also includes the combination of in situ[16] and remote sensing measurements as part of the development of a global observation strategy. Land-based networks with remote sensing capability (e.g. water vapour lidar, microwave radiometers, radar) have great potential for the rapid application of new technologies. German companies play a leading role in the development of these complex instruments. Finally, satellite missions must perform crucial work on improved measurement of key parameters (e.g. precipitation).

5. Air quality and climate change

Air quality and climate change are closely connected. Many air pollutants, such as certain trace gases and aerosols, are also relevant to the climate because they directly or indirectly affect the radiation budget of the atmosphere.

Conversely, climate change also affects air quality due to e.g. changes in air temperature and precipitation. In addition, regional weather conditions are affected, which, in turn, impact the transport of pollutants and atmospheric processes such as chemical reactions or the removal of air pollutants. Chemistry-climate interactions may mutually reinforce each other if, for example, additional biogenic hydrocarbon emissions are caused by warming. Or they may work against each other, when the increased emission of sulphur dioxide leads to a cooling of the atmosphere. At the regional level, in particular, many connections between air quality and climate can be seen, which are often overlooked in global averages. For example, aerosol-cloud interactions have a recognisable effect along shipping routes, in the form of contrails or so-called pyrocumuli (fire clouds).

Although research in recent years has achieved a fundamental understanding of many chemistry-climate interactions, the quantification and prediction of these effects remain beset by major uncertainties. Many processes interconnect with widely varying timescales and continue to be too poorly understood to reliably depict them in models.

The close relationships between the various components of the climate system will require better cooperation between widely varying disciplines in the future. In addition, there is a need for targeted measurements in laboratory and field experiments to obtain reliable forecasts and projections of future regional climate change and air quality. Research is also needed in the integration of the various observation systems with models and in the development of statistically robust metrics to identify and quantify interactions and their changes as well as in the development of detailed process models for important interaction processes

Only by using a combination of measurements and model predictions will it be possible to derive the necessary foundations for decisions on effective and efficient climate and air pollution control. This research must be coordinated at the international level, as no nation can tackle these massive challenges alone. Ultimately it is a matter of establishing a global observation system.

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6. Greenhouse gas cycles in the climate system

The increase in three of the most important climate change relevant atmospheric greenhouse gases - carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) - is determined by two processes: by direct anthropogenic emissions and by the future development of natural sources and sinks of these gases.

Current Earth system models can only describe greenhouse gas cycles to a limited extent, as significant information about biogeochemical sources and sink processes is either lacking entirely (e.g. in the case of permafrost dynamics) or only partially available (e.g. in the case of soil respiration, nutrient limitation, the influence of extreme events, the influence of ocean warming, ocean stratification and ocean acidification on the marine biosphere). As a result, different Earth system models produce very different outcomes for the same emission scenario.

There exist already numerous research initiatives aimed at reducing these uncertainties. However, there is a need for significant research into:

- process studies (in situ and under controlled conditions),
- the maintenance and expansion of regional and global observation systems to long-term and systematic recording of greenhouse gas budgets, as well as
- the development of the next generation of biogeochemical modules in Earth system models (coupling of the carbon cycle with water and nutrient cycles, species diversity of terrestrial and marine biospheres, age structure of vegetation, three-dimensional permafrost dynamics).

These initiatives must be combined into a long-term research strategy, as many relevant biogeochemical processes only become identifiable in natural climate variability after five to ten years or more.

These initiatives must be combined into a long-term research strategy, as many relevant biogeochemical processes, such as the adaptation of ecosystems, only become identifiable in natural climate variability after five to ten years or more. Furthermore, anthropogenic changes can only be reliably separated from natural variability through sufficiently long and systematically collected time series.

Climate projections demand that the anthropogenic effects on greenhouse gas budgets should be included to a much greater extent than previously.

Climate projections also demand that the anthropogenic effects on greenhouse gas budgets should be included to a much greater extent than previously. This includes the development of an observing system for quantitatively measuring anthropogenic emissions with high temporal and spatial resolution. This relates not only to long-lived greenhouse gases, but also to the vast number of volatile gases and aerosols (particularly through the extraction and processing of fossil fuels, including among others fracking).

In addition, better understanding is required of how the massive global increase in agriculture, pasture farming and forestry as well as the advancing urbanisation are affecting ecosystems and their functions in the regional and global climate system, with far-reaching effects on greenhouse gas sources and sinks. Due to the lack of process understanding, consideration of these effects in Earth system models is in its infancy.

II Dealing with climate risks

Climate change represents a particular challenge to society in two respects. First, the impacts of increasing greenhouse gases are subject to a time lag. Only decades, if not centuries, after their emission will their drastic effects on the climate manifest themselves. Second, the effects of climate change differ both regionally and locally. Both aspects are climate impacts and can be interpreted as distributional conflicts.

The long-term nature of climate change leads to distributional conflicts between the generations, whereas the regionally varying effects of climate change may contribute to conflicts within a single generation. In neither case is it possible to clearly identify the dimensions this distributional problem will assume.

Accordingly, social decisions on how to deal with climate change are confronted with two kinds of uncertainty. First, model-based projections of climate change and its impacts are in many cases beset by large uncertainties. Second, the effects on human society are particularly difficult to estimate. The economic and social consequences of climate change lie in the future and are closely linked to the way a society develops in technical, social and economic terms. To a high degree, the dynamics behind these societal processes are principally unpredictable, meaning that the effects of climate change on societies in the distant future are difficult if not impossible to assess. However, rational societal action requires research to better describe and constrain uncertainties about the effects of climate change.

Model-based projections of climate change and its impacts are in many cases beset by large uncertainties. The effects on human society are particularly difficult to estimate.

Climate risks as a social challenge have been described and discussed[17] from many angles. In this discussion, the predominant issue is to establish the social decisions required to react responsibly to the climate risks described. In this discussion, climate risks and knowledge about climate risks have always been taken as a given. But the task we face now is that of identifying systemic climate risks that may have been overlooked and of coming up with better-quality information about the probability and distribution of previously identified climate risks. The implications for researchers dealing with climate issues are as follows: How can integrated climate research and climate impact research produce more and better information about the future evolution of climate change, including its social effects, while at the same time more accurately characterising the uncertainties associated with these developments? And how can research come up with viable options to assist governments, businesses and civil society in managing climate change responsibly?

1. Determinants of climate risks

Risk is defined as the probability of the occurrence of a specific event and the potential damage that this event may cause. This includes both direct damage (e.g. damage to buildings in the event of a flood) and indirect damage (e.g. medium-term impairment of regional commerce following lengthy disruption of transport connections and trans-regional effects in a connected world). Over the long term, climate change may be accompanied by political destabilisation or the loss of trust in political institutions, both of which may threaten prosperity. The identification of climate risks requires both quantitative statements about the probability of the occurrence of specific changes to the climate system and an evaluation of the resulting potential damage. Methods for quantifying risks reach their limits at points where, despite intensive research, the probabilities and the level of damage remain uncertain. These are risks with global effects, interacting in a complex network with other risks. They are virtually impossible to describe with linear models of cause-and-effect chains, the effect patterns associated with them are rather stochastic and chaotic. These so-called systemic risks pose a challenge for ethics and for the social sciences. Alternative, more qualitative definitions of these risks, as used for example in the IPCC Assessment Report, attempt to deal with this problem[18]. But in doing so, they create new challenges for interdisciplinary climate research. To date, there have been few approaches that have developed rules for dealing with systemic risks. The precautionary principle is one such possibility, but it would need to be converted into practical regulations and climate policy instruments.

The determination of the expected future costs and benefits of climate change requires cooperation between a range of scientific disciplines and simulation models.

The quantification of expected future costs and benefits of climate change requires cooperation between different scientific disciplines and the coupling of simulation models depicting the various chains of effects associated with climate change in the form of projections. The cross-sectoral integration of damage (through monetisation or other indicators) and its operationalisation are also based on value judgements and/or societal negotiation processes that need to be stated explicitly. The investigation of chains of effect begins with projections of changes to the climate system undertaken with the aid of climate models. This information forms the basis for projections of climate impacts, which in their turn are then either translated into the possible costs and benefits of climate change via economic models or described by means of qualitative statements from social-scientific analyses. In each of these approaches to the analysis of climate change, the modelling is confronted by uncertainties that are either caused by an inadequate understanding of the system (epistemic uncertainty) or by their very nature are not susceptible of reduction because the system itself is stochastic (aleatoric uncertainty).

Despite these uncertainties, it is in the interest of society to evaluate the effects of climate change in order to obtain options for action.

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It must be taken into account that climate effects may occur over a long period of time. Some climate impacts, such as a rise in sea levels, evolve over decades and centuries, others, such as increased occurrence of extreme events, may occur over shorter periods. Climate impacts can also trigger cascading processes or display feedback phenomena. For example, the rise in sea levels is frequently accompanied by the penetration of salt water into the groundwater, which has a detrimental influence on the economic value of coastal regions. This may lead to relocation, which in turn can create problems at the new location. Such processes are difficult to identify in advance and, due to the paucity of underlying data, even harder to quantify. If in such cases it is not possible to precisely characterise the events to be expected, the social sciences are called upon to develop methods and strategies for dealing with systemic uncertainties associated with these situations.

The risks of future climate change are only one aspect of a wide-ranging global change. Accordingly, the risk assessment of climate change must explicitly take into account interaction with other social and economic developments and the risks those developments involve.

Some societies already are vulnerable for other reasons and may be more seriously affected by climate risks than resilient societies which can adapt more flexibly to climate change. It may then be more advantageous not to engage in separate investigations of climate change and the adaptation processes associated with it but to view social development processes in a systemically integrated way. The Sustainable Development Goals of the UN dovetail these aspects of the transformation of societies on the one hand and nature on the other.

Another aspect are regionally beneficial climate impacts which must be included in an overall analysis. For example, there are likely to be more areas at high latitudes that will become potentially suitable for agriculture, a factor that will open up new economic opportunities.

So far, the varying regional impacts of climate change and the effects associated with it have been difficult to predict. But today it is clear that there will be winners and losers, both within countries and from one nation to another. Despite the inevitable uncertainty about the distribution of advantages and disadvantages, responsible management of climate change also requires an assessment of these changes.

Ultimately, climate-risk evaluation touches upon the question of intergenerational and intragenerational justice.

There is no such thing as a globally uniform framework for climate risk assessment. Social circumstances differ widely, and evaluation must take account of this fact. Regional variations in climate change affect societies with different economic structures, cultural characteristics and levels of risk aversion. Even where the same natural changes are involved, it is probable that the societal evaluation of economic or ecological effects will vary. In addition to cultural variations in classification, priorities will also differ, both with respect to short-term goals such as economic development and long-term objectives such as climate protection. Ultimately, climate-risk assessment touches upon the question of intergenerational and intragenerational justice. This challenge concerns particularly the social sciences, since differing social priorities in the evaluation of a global problem such as climate change also raise ethical questions about the responsibility for its control.

2. How can climate research and climate impact research contribute to responsible management of climate risks?

As is true of projections or model-based scenarios of social and economic development, climate models and climate impact models are invariably subject to a certain degree of inherent uncertainty. Some climate change phenomena will defy quantification as systemic risks and will only be illustratable in their possible manifestations. Regardless of these uncertainties, social decisions on climate protection and on adaptation to climate change will have to be taken. Interdisciplinary climate research and climate impact research can help improve the management of these risks by focusing their research activities on the societal needs in dealing with these risks. This involves more accurate description and, where possible, quantification of risks that have so far been inadequately registered. One example is the spatially and temporally correlated occurrence of extreme events or cascading risks. Another urgent task will be to identify and gradually reduce the uncertainties associated with high levels of risk.

Research should concentrate on climate phenomena where the information deficit is likely to be accompanied by high societal damage.

Research priorities should be determined by the components of uncertainty about climate impacts on the one hand and by the resulting monetary and non-monetary costs on the other, and with regard to discerning potential development paths for the future. In other words, the climate phenomena we know least about should not automatically be assigned the highest research priority. Instead, research should concentrate either on climate phenomena where the information deficit is likely to be accompanied by high societal damage or on instances where a decision on a particular development path needs to be made promptly, because path dependencies will make it difficult to change course at a later stage.

Conversely, major damage that can already be predicted with relative precision requires no further identification or quantification. Instead, research should focus on damage involving the greatest uncertainty about the probability of its occurrence and potentially serious enough to warrant prevention at all costs. Research of this kind should be geared to the needs of society and not to the interests of scientific discovery.

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A precondition for this kind of prioritization is to jointly identify the natural as well as societal aspects of climate risks. This process of co-design of research agendas[19] requires interdisciplinary cooperation between natural scientists and social scientists plus transdisciplinary cooperation with other actors. The natural sciences can pinpoint where more precise statements about the probability distribution of specific climate changes and biophysical impacts can be achieved through further research, may it be in terms of the nature of these change processes or the temporal course and geographical distribution they display. The social sciences, for their part, can identify economic and social effects (including possible cascades), assess the resulting damage and indicate development paths with risk-minimising potential. Ultimately, the prioritisation of research activities should also include a valuation of the societal significance of various climate change phenomena by actors from other fields.

Accordingly, the strategy behind the creation of a future research agenda for dealing with climate risks needs to be carried out in a discursive process of research that is both interdisciplinary and transdisciplinary. It should be noted that this statement refers solely to research for improving the management of climate risks, not to all research on climate change itself. The improvement of our understanding of the climate system and its feedbacks within the Earth system, as well as research regarding the better understanding of social development processes, take place in the domain of basic research. As such, they do not require special justification. They can and should take place hand in hand with solution-focused research.

The strategy behind the creation of a future research agenda for dealing with climate risks needs to be thrashed out in a discursive process.

The process of co-design in research, politics and practice should be seen as an iterative process in which research and practical implementation are involved in a permanent learning process[20]. Just as important as the definition of the content of research priorities is a design of the process in which the various actors (academic research, political and economic decision-makers, various institutional levels) can communicate productively.

3. Potential areas of research

Without pre-empting the co-design process, some general areas of research can be identified which focus on social risks and would be easier to tackle with the aid of progress in climate research. Here are some examples:

Identification of the effects of climate change within the context of global change

Observations of social challenges affected by climate change are also dependent on other social changes occurring parallel to climate change (different construction methods for buildings with new technologies, greater vulnerability of complex infrastructures, agglomeration of economic activity or settlements in areas potentially at risk from climate change, intergenerational changes in value systems). This generates two research issues. On the one hand, determining the effects of future climate change on economic development and on the environment – and hence on human well-being as a whole – cannot be conducted independently of social and technological changes. The costs of climate change are thus conditional on the overall process of global change. This is a challenge for interdisciplinary research. On the other hand, it is important for focused and efficient social decisions to keep the various causes behind the impacts of climate change separate from one another. Only then can cause-based prevention of and adaptation to climate change actually take place.

Energy security and climate change

The secure availability of energy is the cornerstone of economic development. The availability of energy can be both negatively and (sometimes) positively affected by various aspects of climate change. As an example we can take the acceleration in the expansion of renewable energy sources with the specific purpose of preventing greenhouse gases. These energy sources are coupled either indirectly (renewable biological resources, hydropower) or directly (wind and solar energy) to the weather or climate. Accordingly, changes in weather variability caused by climate change may well affect the spatial and temporal availability of renewable energies. More frequent and more violent storms could impair the safety of grid-connected wind energy, extended dry periods could force limitations of power plants due to waste heat problems. The associated need to adapt both the networks and demand from electricity consumers requires interdisciplinary and transdisciplinary cooperation if the challenges of the "energy transition" are to be coped with successfully.

Evaluation of extreme weather events in the atmosphere, hydrosphere and along coasts

Extreme events reinforced by climate change are often more threatening for societies than slowly progressing climate change. Accordingly, the probability of occurrence and the effects of extreme events in the atmosphere, in the hydrosphere and along coasts count as socially relevant and essential information, both as they relate to the present and to expectations for the future. To date, much work has been done to record the statistics of extreme events in accordance with their geophysical variables. The task now is to identify significant changes in probability distributions and occurrence probabilities and establish plausible causes for these changes. As the determination of probabilities for extreme events has its limitations, alternative information on the effect and significance of extreme events needs to be generated. This also includes the evaluation of individual events. The ethical dimension will play an important role in the evaluation of potential but hardly quantifiable events and the management of such eventualities.

Identification and management of conflicting objectives in risk management

Strategic decisions on the preventive management of climate risks at all political levels must anticipate and tackle conflicting objectives (such as increased residential density versus green areas). This calls for approaches that analyse the various nexuses involved in an integrated manner and offer information for appraisal processes and new options for action. For example, in the event of changes in the frequency and intensity of heavy rain events, it will be essential to devise new solutions and tools to support planning decisions on domestic water management.

Assessing the social and economic consequences of climate change

While integrated assessment models are in standard use for the quantification of the global costs of preventing emissions, there is much less systematic quantification of the economic and social consequences of climate change. Notably the risks posed by extreme spatially and temporally correlated events and their long-term impacts are not covered by the models currently available. For comprehensive risk analysis, new global and regional model-based approaches both from the natural sciences and the social sciences need to be developed to compare and contrast the costs of reducing emissions with a reliable estimate on the economic consequences of climate change

III Climate research in democratic societies

Climate change is an issue of great societal importance, as it affects all areas of our lives. The demand for scientific knowledge to deal with climate change is growing. As a result, climate research is subject to expectations from policy-makers, businesses and civil society to provide relevant knowledge, especially when the focus is on delivering reliable predictions and projections about future developments, assessing risks and highlighting the spectrum of available response options.

Scientific assessments of the risks of climate change may have a decisive influence on decision making in politics, business and civil society.

These scientific assessments of the risks of climate change may have a decisive influence on decision-making in politics, business and civil society. Moreover climate research – like all other areas of science – does not take place in a "societal vacuum". Researchers are always members of a given society and they perform their scientific work in a world characterised by moral values and assumptions about normality.

The distributional conflicts resulting from climate change, addressed in Chapter II, require a debate about values such as those of international and intergenerational justice. On the one hand climate research has a contribution to make, but it cannot decide this debate. On the other hand political institutions provide science with resources to enable them to make decisions based on scientifically valid results. It is this very close reciprocal relationship that makes climate research in democratic societies subject to considerable public scrutiny.

These preliminary considerations give rise to three issues which should be investigated more fundamentally and systematically in future.

Climate researchers and their roles

The roles of climate scientists (the "view inwards") have been discussed to some extent in the past, for example in connection with the model of the "honest broker"[21]. However these considerations should be reviewed and expanded upon in relation to the specific situation of climate research. These analyses invite climate scientists to be more self-aware, with respect to the complex relationship between policy-relevant science and democratic societies.

Structural change in climate research

The growing demand for information about the social impacts of climate change and potential response options calls for extending the range of issues addressed by climate research, for including new scientific disciplines from the social sciences as well as developing new forms of interdisciplinary and transdisciplinary cooperation[22].

Providing politically relevant knowledge

The third issue involves a change of perspective from climate research itself to its possible target groups in politics, businesses and civil society ("the view outwards"). It asks what information needs to arise from the point of view of these audiences and what challenges emerge for climate science to provide relevant knowledge in a scientifically reliable and credible way.

1. Climate researchers as social actors – the "view inwards"

The "view inwards" directs the research focus towards the complex texture between the production of policy-relevant knowledge and its public uptake and acceptance. The aims here are to invite climate scientists to reflect what role(s) they do and can play in democratic societies.

Social sciences and humanities – for example in fields such as the history and sociology of science and technology studies – have been discussing these issues for many years now. What has been lacking thus so far, however, is a systematic review of these findings. The key purpose of future research in this area is to shed light on the prerequisites for and possibilities of producing climate-relevant knowledge and to make these insights available to climate researchers.

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Four topics emerge under this heading:

Knowledge production

One of the key challenges climate research faces is that of dealing with complexity, uncertainty as well as a plurality of scientific viewpoints. This is why growing importance is attached to the issue of how the scientific community establishes consensus, deals with dissent and warrants quality and how science is integrated across scales, scientific disciplines and epistemologies.
The challenges climate research faces raise a number of questions: How do the cultural foundations influence processes of knowledge production? Does this give rise to problematic research practices which ought to be reconsidered?

Institutional design

The specific institutional configuration of climate research shapes its degree of visibility, the way it sees its role and the way it is perceived by others.
The questions that arise are: What insights can be gained about the functionality or dysfunctionality of various institutional forms of research? What are lessons to be learnt and to what extent can possible reforms be derived from these insights?

Exchange of knowledge

A further issue has to do with the dynamics of and conditions for the exchange of knowledge between climate research and politics, business and the media. This also involves competition with different forms of knowledge, such as practical knowledge, cultural narratives or media representation in the form of worst-case scenarios or even climate catastrophe reporting. The pertinent questions are: What are the dynamics and patterns of exchange between climate researchers and other societal actors? And how significant is the competition between science and different forms of knowledge?

Sustainable science communication

Finally, science has to deal with the challenges of sustainable science communication.One of the main assets of science – broad acceptance of scientific knowledge by society – should not be put at risk either by politicised communication or by becoming involved in forms of mass media communication without careful consideration. The question is: How can credible science communication be reconciled with the logic of media discourse and political decision-making processes?

Research on these questions should clarify the way climate researchers see themselves in terms of their role as societal actors. It should also contribute towards enhancing climate science communication and scientific policy advice.

2. Structural change in climate research – recognising the spectrum of the climate issue

National and international climate research has changed significantly over the past two decades. One of the reasons for this is the evidence of impacts of climate change and, in connection with this, the ever more intense debates in the political sphere about adaptation and mitigation options. The significance of these societal issues is growing, and with it also the importance of the social sciences in climate research. There is a growing need to inquire the social, political, economic and cultural impacts of climate change, and to understand the consequences of climate change for everyday life. This structural change in the domain of research is also reflected in the last two IPCC Assessment Reports (of 2007 and 2013/14).

For the social sciences, this means that two issues are assuming increasing significance:

Basic research in new areas

A change in perspective is taking place, as it is no longer climate change itself but social dynamics that are the starting point of inquiry.

Basic social science research investigates how climate change is perceived and dealt with by societal actors, organisations and institutions such as the media. It can help to fundamentally reframe climate change as a social, rather than physical, problem. This signals a change in perspective, as it is no longer climate change itself, as in the natural science research, but rather social dynamics – such as cultural patterns of perception, corporate activities, private consumption and political governance – that are the starting point of inquiry. One example is research on agenda-setting processes, that is, the criteria according to which the media or politicians select climate change as a subject to be addressed in the public sphere and to be regulated politically – given that climate change is just one of many potential subjects. Linked to this are studies on the changes that occur in the realm of politics, the media or businesses when climate change is picked up on and dealt with in these realms. Of interest here are the underlying dynamics that drive social developments, whether or not climate change is perceived and dealt with. The study of such processes is key because they shape how options are chosen. It is these dynamics which ultimately determine the options available for implementing climate protection and climate adaptation. Obviously, climate policy is embedded in many other realms of society and must be seen as just one – albeit important – component of the overall system.

The growing importance of interdisciplinary and transdisciplinary research

The demand for sustainability in science and for transdisciplinary or integrated research to tackle the grand challenges of our time such as climate change or the energy transition has been growing in recent years. The terms used vary, and indeed they are not identical. At its core, however, this debate is about the need to get representatives from politics, business and civil society more closely involved in the design of research agendas (co-design) or even in the research itself (co-production). Examples include the EU research programme "Horizon 2020", research on global change ("Future Earth") and the FONA research programme (Forschung für nachhaltige Entwicklung – Research for sustainable development) of the German Federal Ministry of Education and Research (BMBF). For several years now a range of experience has been gathered on a practical level and various formats for including non-scientific actors ("stakeholders") have been put into practice. Until now, these different formats have rarely been systematically reviewed. To benefit future research, the different settings of transdisciplinary research must be systematically evaluated and the results packaged accordingly for application in climate research.

The demand for sustainability in science and for transdisciplinary or integrated research to tackle the grand challenges of our time has been growing in recent years.

Two sets of questions arise out of this:
1) To what extent do the existing policy advice institutions serve their intended functions with regard to scientific quality, relevance to decision-making and legitimacy?
2) How should policy advice and climate research be re-arranged in the future in order to take due account of the expectations directed at transdisciplinary research processes?

The results of basic research in new areas as well as of integrated research should ideally also contribute towards the development of new approaches in policy relevant climate research.

3. Providing politically relevant knowledge – the "view outwards"

The information and advice needs of decision makers are context-specific; they usually relate to a tangible problem.

One key challenge for science policy advice is that of tailoring scientific knowledge to the specific information needs of decision makers. These needs are context-specific: they usually relate to a tangible problem in a specific sector, such as flood protection or energy supply, to a specific level (regional, national or global) and to a specific timeframe, taking into account diverse legal settings. In order to tailor scientific knowledge to the needs of different target groups, policy advice institutions need to know – more so than they have up to now – the rules of the game and the modus operandi on the "demand side".

Providing climate services

Initiatives and institutionalizations of climate services have developed to date in a pragmatic, experimental or simply ad hoc way at local, regional and national levels. In Germany, for example, it is now possible to access an entire range of established institutions. Reviews of established scientific knowledge, derived from the working methods of the IPCC Assessment Reports, have also proved their worth in practice for regional approaches[23]. Climate services dealing with specific local requirements are generally able to bring the public and decision makers "on board" and should be broadened and developed further as part of a dialogue between equals.

The following requirements should be met when taking this forward:

- Better and publicly accessible data on regional climate change.
- More accurate assessments of regional changes, assigned to global, regional and local impacts, to enable better planning of the scope and timeframe of adaptation measures.
- Opportunities for dialogue at regional and local level to facilitate transdisciplinary exchange; accompanying research by social scientists is indispensable here.

Policy Assessment

The focus on technical solutions often blocks out problems of acceptance by society – and yet such problems are set to become more significant.

There is also a growing demand for assessments of policy options and pathways for responding to climate change that are innovative, feasible and acceptable. The aim of these policy assessments is to explore different possible solutions rather than determining and substituting decision-making. Two of the key gaps in research are the impacts of different climate protection policy options and critical ex-post analyses of policy instruments such as the European emissions trading scheme. The focus on technical solutions often blocks out problems of acceptance by society – and yet such problems are set to become more significant, as demonstrated already by the debates surrounding fracking, geo-engineering and negative emissions.

In addition to questions of technological and economic feasibility, questions must also be asked about the political practicability and legitimacy of climate policy options. This kind of policy analysis requires basic research that generates understanding of the way policy measures effect one another reciprocally as well as methods suited to an integrated assessment of them. In addition to evaluating the options for action, a rational debate about value judgements relating, for example, to international and intergenerational justice and the distribution of risks is also required (in this regard see section (1) of this chapter and Chapter II). Here, the natural and social sciences can help to identify differing implications associated with putting certain assumptions about values into practice. For example, calls to implement equality may, due to the resulting unwanted side effects, encourage critical reflection about initial value assumptions. This kind of policy assessment requires basic research that generates understanding of the mutual trade-offs and synergies between policy goals and instruments as well as approaches suited to an integrated evaluation.

Mapping the landscape of policy relevant science

During the last decades, we can observe the emergence of a broad range of applied research, think tanks and advisory bodies in the field of climate change. At the same time policy-relevant information is split and fragmented across expert communities, policy sectors and levels of decision-making. This diversity has led to a rather unstructured science policy advice sector at national and international level. It would be worthwhile to map it and to evaluate both the successes and failures of existing science policy advice services.

It would be worthwhile to map existing science policy advice and to evaluate both the successes and failures.

The following aspects should be explored in this regard:

The demand for policy relevant knowledge

What exactly are the specific information needs of various target groups such as policy makers, businesses and civil society? What information is relevant and what are the knowledge gaps as far as the target groups affected are concerned?

Internal logics of societal processes

How do societal decision-making processes take place? What are the criteria according to which political options are assessed, upon what basis are decisions made and what role does scientific evidence play in this? Which particular challenges arise when there is major scientific uncertainty and the potential for political conflict?

Mutual understanding

How can the societal demand for knowledge and the supply of knowledge by scientists be brought into alignment? What trade-offs might emerge between scientific and political expectations during the process of providing and translating policy relevant knowledge? What are procedures, processes and institutional designs to facilitate a productive exchange and how can they be institutionalized?

Institutional framework conditions

There is a growing need to pay attention to the ways how science and expert bodies are governed. The institutional design of the IPCC has already been investigated relatively comprehensively, and in many places the IPCC model has been copied. However this model is tailored to the information needs of multilateral decision-making structures in international climate policy. But what role can climate science and expert bodies play in the fragmented and polycentric architecture of the future climate regime? After all, new forms of assessments and policy advice have already been established from the global to the local level. Still their approaches and institutional designs are relatively unexplored. Future research could provide information here on alternatives to the established forms of policy relevant research and policy advice.

Quality assurance

How can the quality of the processes and results of climate research and policy advice be secured? What alternative quality assurance procedures exist – apart from the classic peer review – for incorporating alternative sources of information that are frequently relevant and of high quality but have not been reviewed in accordance with traditional scientific procedures ("grey literature")?

The question is: How can science participate in the debate about social transformation?

As a first step, an empirical review of existing knowledge should be conducted as part of a broader scientific assessment. There is a considerable need for research that examines and assesses the established science policy advice sector. Factors that have a major influence on policy advice processes should be investigated in particular. Those procedures and aspects of the institutional framework conditions that contribute towards optimising the process and outcomes of policy advice should be identified on this basis. The following questions must also be posed: Can scientists participate actively in the debate about societal transformation without leaving themselves open to accusations of abandoning scientific integrity? How can these societal learning processes be formalised to deal with complex societal challenges in a credible and legitimate manner?

Notes

[1] IPCC: Intergovernmental Panel on Climate Change. Initiated in 1988 out of the environmental programme of the United Nations (UNEP) and the World Organisation for Meteorology (WMO) to summarise and assess the state of scientific research for political decision-makers. Most recently, in 2013 and 2014, the four volumes of the Fifth Assessment Report on the physical science basis of climate change (Volume 1), climate impacts (Volume 2), climate protection (Volume 3) and the synthesis report (Volume 4) were published. In the "Summary for Policy Makers of the IPCC Assessment Report 'Climate Change 2013 - Physical Science Basis'", the statement on page 13 reads as follows: "Human influence on the climate system is clear. This is obviously due to the rising greenhouse gas concentrations in the atmosphere, the positive radiative forcing, the observed warming and understanding of the climate system. {2-14}"; http://www.de-ipcc.de/_media/IPCC_AR5_WG1_SPM_deutsch_WEB.pdf

[2] WCRP: World Climate Research Programme is an international programme at UN level for research on the climate and Earth system. Likewise, IGBP, International Geosphere-Biosphere Programme, which focuses on research on global change in the Earth system. The international cross-sectional platform "Future Earth" coordinates research topics on the transformation to a sustainable society.

[3] Projections are simulations of the future or a range of different "futures" – rather than prognoses (forecasts, predictions).

[4] Integrated research is an overarching term for inter- and transdisciplinary research. Interdisciplinarity refers to the joint research of scientists from different disciplines; transdisciplinary research to the cooperation with partners from business, politics and civil society. Derived from Anglo-Saxon practice, the terms increasingly used include co-design (joint development of the research agenda) and co-production (joint production of research) (see Mauser et al. 2013).

[5] The basic accepted strategy for dealing with climate change is as follows: Mitigation of climate change, known as climate protection, in particular through a low-CO_2 energy system and simultaneously adaptation to the inevitable climate change, e.g. by raising the dike heights.

[6] Climate system components include: the atmosphere, ocean, land areas and the cryosphere, including the biosphere on land and in the sea.

[7] Some processes cannot be resolved in models. These processes are parameterised, meaning that information is described at the grid points of the model (sampling points) with the aid of measurement values or theoretical concepts.

[8] Cryosphere: the whole of the frozen water on Earth, particularly sea ice ("pack ice"), glaciers, ice shelves ("ice crust"), permafrost soils (permanently frozen ground) and snow cover.

[9] Biosphere: the area on planet Earth where life occurs. It ranges from the upper layers of the Earth or surface of the Earth (lithosphere) to approximately 60 km into the atmosphere (mesosphere).

[10] Volcanoes and anthropogenic effects are counted among the external drivers, as they change the composition of the air and therefore, like the sun, the global radiation budget of the Earth.

[11] Sources release greenhouse gases into the atmosphere and sinks absorb them from the atmosphere and store them.

[12] El Niño / Southern Oscillation (abbreviated: ENSO) refers to a coupled circulation system of the ocean and the atmosphere in the tropical Pacific region which affects, among other things, the temperature of the sea as well as the number and strength of storms and precipitation. The circulation system can strongly fluctuate within a year and from year to year, thereby contributing to natural climate variability on Earth.

[13] Acidification refers to the pH value, which indicates the strength of an acid or basic effect in an aqueous solution. The midpoint “7” is regarded as neutral. Sea water, with a pH of 7.5 - 8.4 is slightly basic. However the pH value has already decreased by an average of 0.11 units compared to the pre-industrial period due to the absorption of CO_2, and has therefore shifted towards the acidic range. This process will persist for as long as the CO_2 concentration in the atmosphere continues to increase.

[14] Proxy data are indirect climate indicators, which permit conclusions about prehistoric climate or past conditions in the atmosphere to be drawn. This could include for example tree rings, pollen, ice cores or information about the state of glaciers.

[15] Climate sensitivity is a theoretical value. It describes how strongly the Earth would warm if there was a doubling of the carbon dioxide content of the atmosphere compared to the pre-industrial level (of 280 ppm). The Fifth Assessment Report of the IPCC specifies a range of 1.5 to 4.5 degrees Celsius, due to uncertainties in this area.

[16] in situ = locally: This means measurements with aircrafts, balloons, measuring towers etc., which can take measurements directly in clouds – in contrast to remote sensing, which must view and measure these clouds via satellite from a great distance. Both methods have advantages and disadvantages, which is why they are combined.

[17] See: IPCC Special Report “Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation”; see: German Advisory Council on Global Change: World in Transition: Strategies for Managing Global Environmental Risks, Annual Report 1998

[18] See IPCC, 2014 Summary for Policy Makers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. p. 3, Figure SPM 1

[19] This process was described in detail in: W. Mauser, G. Klepper et al. (2013) “Transdisciplinary global change research: the co-creation of knowledge for sustainability”. Current Opinion in Environmental Sustainability, Volume 5, September 2013, pages 420-431.

[20] The Fifth Assessment Report of the IPCC makes specific proposals in this regard.

[21] The term was introduced by the social scientist Roger Pielke Jr. (2007) and means the scientist as an honest broker between policy options.

[22] Inter- and transdisciplinary, see note 4.

[23] An example is the report on climate knowledge in the Baltic area titled “Assessment of Climate Change for the Baltic Sea Basin” (BACC).

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About us

The German Climate Consortium (Deutsches Klima-Konsortium, DKK) brings together major actors in German climate research and climate impact research. The federation was established by climate researchers in 2009. Since then more than 20 world-wide renowned research institutions have formed links through the DKK. These include universities, research institutes outside university and higher federal authorities.

DKK views itself as a platform for climate research and as a central point of contact for the public as well as for decision-makers on issues of the climate and climate change. Under the motto "research for the society, the economy and the environment", the DKK promotes policy relevant climate science. The office is located in Berlin near the government district.

Mission Statement

We represent the major actors in German climate research and provide an integrated platform for our members.

We represent the interests of our members in the strategic planning of climate research in Germany and the EU.

We promote the exchange of information and support interdisciplinary cooperation in climate research.

We pursue an active dialogue with decision-makers and consequently contribute to the development and formulation of research funding programmes.

We provide the media and society with information on climate research in order to contribute to a better understanding of climate change.

We impart knowledge of climate research to decision-makers and consequently make a fundamental contribution to the strategic alignment, formulation and implementation of climate policy.

In addition, the German Climate Consortium advocates the support of the new generation of scientists and contributes to the thematic focus of climate research through its working groups.

The position paper "Perspectives on Climate Change 2015 to 2025" was unanimously adopted on 07th May 2015 by the ordinary general meeting of DKK.

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