2 — The CH2014-Impacts approach to scenario-based impact quantification

2.1. INTRODUCTION

Quantifying climate change impacts requires a model of the linkages by which climate affects the environment, the economy, and society. Of the multitude of relevant linkages considered in this report, each is treated with a dedicated **impact model**. Common to this variety of tools is the need for an equally quantitative description of the evolution and future states of climate as an input. The CH2011 **climate scenarios** provide such information for the key variables mean surface air temperature and precipitation (CH2011, 2011), derived from climate simulations with a spatial resolution capturing Switzerland's main topographic features.

Climate simulations are encumbered by substantial uncertainty due to the limited understanding of climate change, under-representation of physical processes, and largely unpredictable natural variability. Such **climate uncertainty** concerns the simulation of global change and is further accentuated in the local assessment for Switzerland. CH2011 (2011) represents the climate uncertainty range by an upper, a lower, and a medium estimate each for temperature and precipitation changes.

The appropriate time horizon for an impact assessment varies with the topic considered, the stakeholders concerned, and the nature of the planning and management decisions involved. The climate system itself limits the choice of time periods for which impacts can be reliably quantified, as shorter periods or periods closer in time would be dominated by natural variability. The three **time periods** provided by CH2011, each representing a 30-year average, are a compromise between these limits and needs in order to allow for a short-, mid-, and long-term perspective over the 21st century.

The scale of future anthropogenic climate change is governed by the amount of CO_2 and other greenhouse gases and pollutants emitted to the atmosphere. This great unknown depends on socio-economic dynamics as well as political choice about greenhouse gas emission reduction (commonly referred to as climate change mitigation). In the context of the Swiss impact assessment of CH2014-Impacts, global climate policy is largely an external factor, and may be best considered in terms of political uncertainty. Uncertainty along these lines is bracketed by **three greenhouse gas scenarios**, which range from unrelenting emission growth to ambitious climate change mitigation.

In summary, the full impact assessment process presents itself as a sequence of steps along a causal chain of greenhouse gas levels, climate change, and impacts. With each step, new dimensions of the problem come into play. The complexity common to all impact assessments is structured using the heuristic concepts of greenhouse gas scenarios, time periods, and climate uncertainty levels.

Moreover, estimating an impact of a given climate change is also subject to uncertainty, because reality is represented incompletely in the impact models, and unknown non-climatic factors can play a role. This **impact uncertainty** is expressed in a spread of results when different impact models are applied to the same question.

The choice of a greenhouse gas scenario is fundamental to this kind of impact assessment, as each end result is conditional on it. Any such result makes no claim to predict future events as, e.g., a weather forecast would. To express this conditionality, these results are called **projections**, following an established convention (e.g., IPCC reports). A projection

‹ During summer 2013, melting reduced the ice thickness at the tongue of the Rhone glacier by 3-5 m even with protective cover (entrance of the fleece-covered ice cave of the Rhone Glacier; photo: David Volken, BAFU).

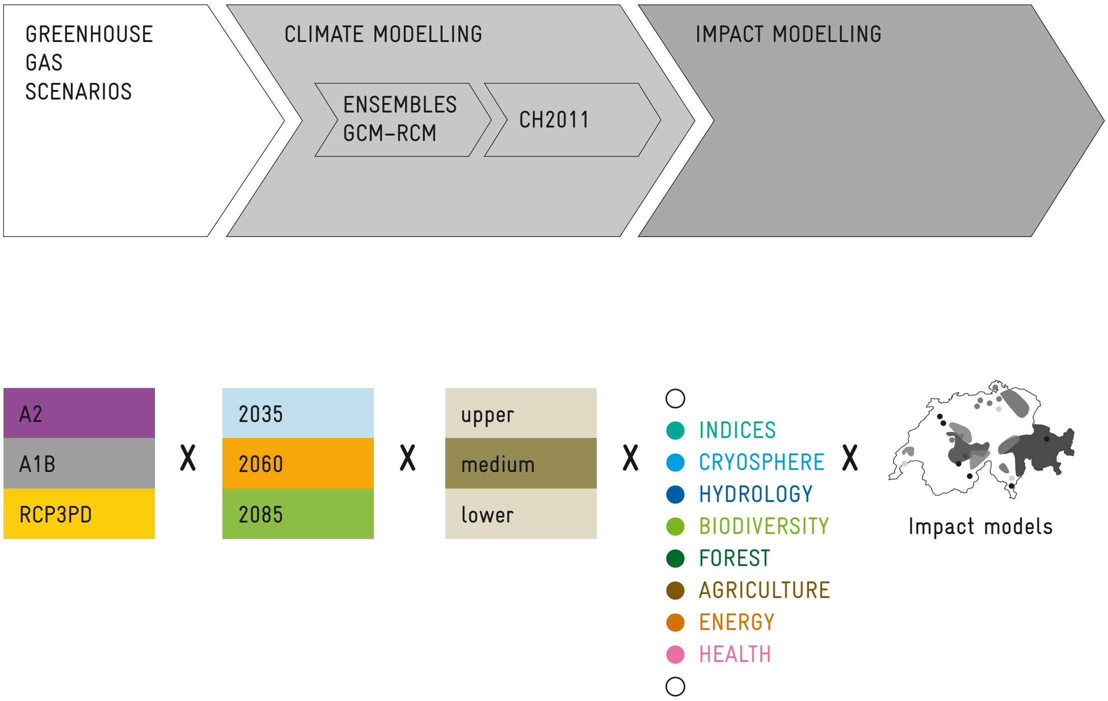

Figure 2.1: Flowchart of the quantitative assessment of climate change impacts showing the stages of an impact projection in the form of an arrow (top), and the heuristic concepts of greenhouse gas scenarios, time periods, and uncertainty levels (bottom).

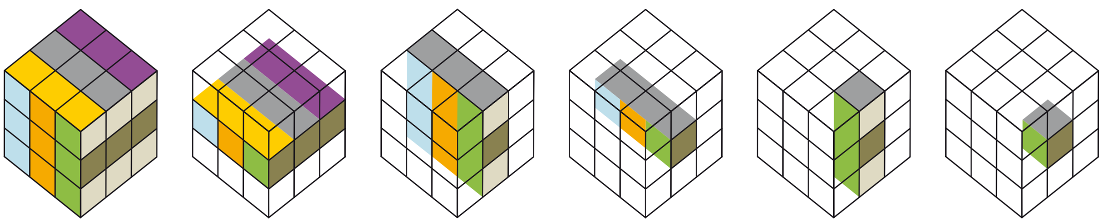

Figure 2.2: The "scenario cube" illustrating the 27 possible combinations of greenhouse gas scenarios, time periods and climate uncertainty levels, and subsets showing possible selective simulation protocols.

can be visualized as an arrow spanning from the greenhouse gas scenario to the final impact assessment (Figure 2.1).

As the collection of climate projections based on a greenhouse gas scenario is called a climate scenario following the usage of the CH2011 report, the projection of impacts can eventually form an **impact scenario**. To justify this term, an impact scenario would need to be representative enough to inform a comprehensive assessment of, in this case, all major climate change impacts in Switzerland. The studies of this report do not yet constitute an impact scenario in this sense, but can serve as building blocks of future scenarios that are yet to be completed.

The dimensions of greenhouse gas scenario, time period, and climate uncertainty, broken down into three levels each, are schematically represented by a **scenario cube** (Figure 2.2). The 27 blocks of the scenario cube illustrate the complete simulation protocol for the impact models. While each individual impact study in this report rests on a similar projection, not all studies take into account the full range of eventualities, exploring, as it were, only a fraction of the scenario cube (Figure 2.2). This limitation is mostly due to limited computational resources, data restrictions, and the tight time frame of the project.

In the following sections, the essential concepts of the CH2014-Impacts assessment approach are discussed in more detail, to guide the reader in the interpretation of the report's results. More specific information about the CH2011 climate scenario data is presented in Chapter 3.

2.2. GREENHOUSE GAS SCENARIOS

CH2011 (2011) considers three greenhouse gas scenarios widely used for climate projections and broadly representative of the literature. These scenarios are based on diverging assumptions about future socio-economical, technological, and political developments, which translate into a range of future greenhouse gas emissions and atmospheric concentrations that are used to force climate models. These scenarios also specify secondary anthropogenic drivers of climate change such as aerosols or land use changes.

- The **A2** scenario (Nakicenovic and Swart, 2000) projects high emissions as a consequence of unchecked population growth and continued reliance on fossil fuels without intervention to reduce climate change. The A2 scenario corresponds in emissions and underlying assumptions to the strongest warming scenario of the Representative Concentration Pathways (RCPs) on which most climate simulations of the IPCC's recent fifth assessment report are based (IPCC, 2013).

- The **A1B** scenario (Nakicenovic and Swart, 2000) represents the midrange of the greenhouse gas scenarios. Lower emissions in comparison to A2 result from a turnaround in global population in mid-century, combined with rapid economic growth and technological development, which lead to a diminishing role of fossil energy. Like A2, A1B does not assume specific climate policy intervention.

- The **RCP3PD** scenario is the lowest of the RCP scenario set (IPCC, 2013) and represented the most stringent climate change mitigation scenario of the literature when it was developed. RCP3PD is originally defined as a path of atmospheric greenhouse gas and aerosol concentrations. It offers an estimated 2/3 chance of limiting global surface temperature to 2°C above the preindustrial average (IPCC, 2013; RCP3PD is referred to as RCP2.6 in the IPCC report, after the level of radiative forcing reached in 2100; here we adhere to the name used in CH2011, 2011). While the underlying assumptions are not part of the scenario definition, they include both moderate increases in driving factors such as population and energy use, and an ambitious and effective mitigation policy.

In the figures of this report, the three greenhouse gas scenarios are color-coded by yellow (RCP3PD), grey (A1B), and purple (A2), respectively (Figure 2.1).

2.3. CLIMATE DATA BASE, REFERENCE PERIOD, AND SCENARIO HORIZON

The common set of input data for the impact models consists of the „Swiss Climate Change Scenarios CH2011" published in 2011, and its later extensions (Chapter 3). The CH2011 scenarios in turn are developed on the basis of the regional climate model simulations from the European-wide ENSEMBLES project (van der Linden and Mitchell, 2009). Some impact models require data extending beyond the Switzerland-specific scope of CH2011, such as the biodiversity study (Chapter 7), or require transient scenarios with high temporal and spatial resolution, such as the study on beech and fir distribution (Chapter 8). In these cases, CH2011 data is augmented by interpolating the scenario periods or by using climate model output directly, after applying appropriate processing steps such as spatial downscaling, etc.

CH2011 (2011) specifies the change in climatological 30-year means of surface air temperature and precipitation with respect to an observational reference period. The 30-year mean is used to represent a climate state as the period is long enough to remove year-to-year variations, but still short enough to capture longer climatic trends (definition by World Meteorological Organization; WMO, 1967).

The reference period used in this report spans the years 1980–2009. This period was chosen for CH2011 scenarios over the widely used standard reference period 1961–1990, in order to enhance comparability with recent observations. This choice implies a difference in the annual reference temperature of about 0.8°C with respect to the period 1961–1990 (Figure 2.3). Any impacts having occurred due to climate change during the two decades separating the different reference periods will not show up in the results of this report. Similarly, the impact of warming since the preindustrial period, which amounts to roughly 1.5°C for Switzerland (Begert et al., 2005), is not included. Comparison of the presented result with earlier studies also requires comparability in the reference periods. This applies, e.g., to comparisons with the CH2050 scenarios (OcCC, 2007), which use a similar reference year (1990).

The time horizon of the scenarios covers the current century in three 30-year averaged periods around the central years 2035 (near term), 2060 (mid-term), and 2085 (long term). The periods partly overlap and are mainly selected for practical reasons to provide projections relevant for near-, mid- and long-term decisions, respectively.

2.4. QUANTIFYING UNCERTAINTY

Science strives to reduce uncertainty by expanding knowledge (although some uncertainties are irreducible). An equally important scientific task is to quantify uncertainty so as to faithfully reflect the bounds of our current knowledge. The ability to show the "uncertainty" of a result is a strength rather than a weakness of any study. The existence of an uncertainty range allows one to devise robust responses by prudent selection of the central, upper or lower estimates depending on whether the focus is on the likely outcome or a less likely but potentially more momentous outcome. In other words, uncertainty ranges allow one to hedge against risks that a best-guess approach might overlook.

The CH2011 climate uncertainty range spanned by "upper", "medium", and "lower" values formally corresponds to the 95% confidence interval inferred from the spread of the underlying climate model ensemble simulations and observed natural climate variability. However, this range captures true climate uncertainty incompletely, due to the limited number of climate models used and incomplete coverage of the relevant processes in the climate system and their respective scientific uncertainties.

Based on expert judgment informed by the current state of climate science, CH2011 (2011) recommends the following interpretation of the climate uncertainty range: the expected chance that actual observed values will fall between the upper and the lower values is two in three for temperatures, and one in two for precipitation. This interpretation is important for comparison with other assessments, for example OcCC (2007), which used uncertainty ranges corresponding to 19 out of 20 cases (i.e., a 95% interval).

Impact uncertainty is quantified as the range of estimates that is consistent with what is known about the underlying influence of climate. This concerns process knowledge, the availability of observations, and the influence of random factors such as natural variability. The impact uncertainty range results either from applying different models to the same process (e.g., in the studies of Chapter 6), or from considering the uncertainty of the model's parameters (e.g., Chapters 11–12).

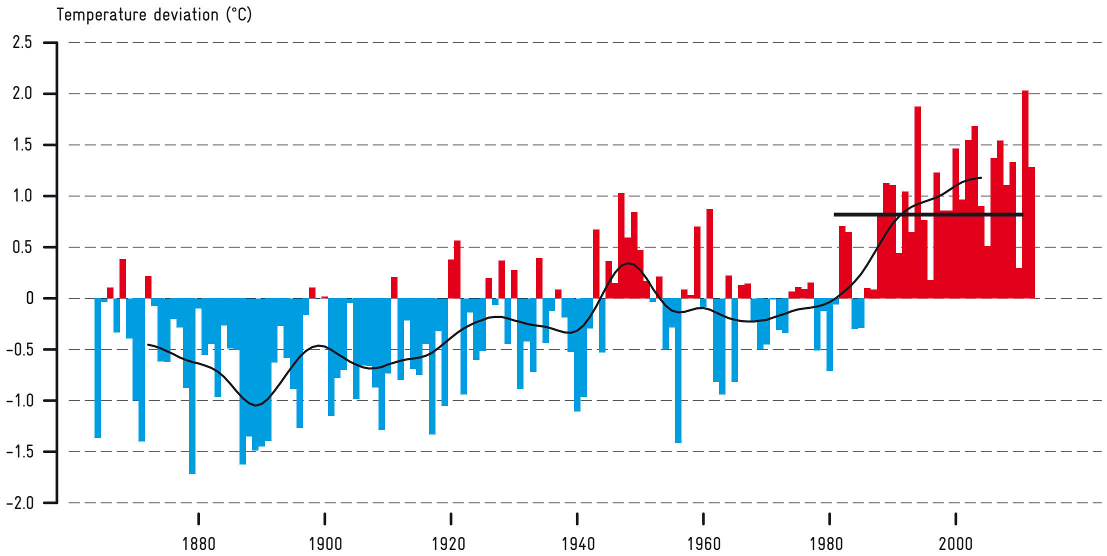

Figure 2.3: Mean annual temperature over Switzerland with respect to the period 1961–1990. The impacts presented in this report are presented with respect to the reference period 1980–2009. The figure shows the mean temperature over the closely corresponding period 1981–2010 (bold black line). The fine black line shows the smoothed (20-year Gaussian filter) mean annual temperature (Begert et al., 2013).

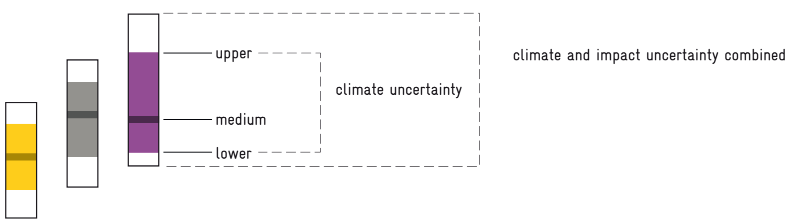

Figure 2.4: Illustration of uncertainty: climate uncertainty which represents the upper, medium, and lower estimates of the CH2011 climate scenarios, and impact model-related uncertainty. Colors identify the greenhouse gas scenarios RCP3PD (yellow), A1B (grey), and A2 (purple).

The quantification of impact uncertainty is relatively detailed in some studies of this report, and partial or missing in others according to the resources at hand. Additionally, non-climatic factors may have a large potential influence on the impact of climate change (e.g., the role of technological development for energy demand in Chapter 10), but are not generally considered in this report.

The CH2011 climate uncertainty levels are illustrated in the scenario cube with olive green shading (Figure 2.2). In the graphical presentation of results, climate uncertainty corresponding to the CH2011 upper/lower levels is shown by colored bars extending from the central estimate (Figure 2.4). The combined range of climate and impact model uncertainty is indicated by an outline, which extends beyond the colored climate uncertainty range when separate information on impact uncertainty is available.

2.5. LIMITATIONS

Apart from the uncertainties introduced above, any impact study faces specific limitations which arise from its methodological approach and affect its implications. Additionally, there are limitations that are common to all assessments and are related to the climate scenarios on which the report rests. According to the definition of climate as the (long-term) statistics of weather, designing a climate scenario involves the specification of the frequency and intensity of all possible weather events in the future, covering in principle all relevant variables.

The approach taken for the CH2011 climate scenarios makes this challenging problem tractable by resorting to strong simplifications: only the mean change in the main variables surface air temperature and precipitation is specified, and the day-to-day fluctuation of weather is borrowed from observations over a reference period (so-called delta change approach, Chapter 3). This approach does not account for possible systematic changes in the occurrence of extreme weather events that would not affect the average climate. Changes in extremes such as heat waves, heavy precipitation, etc., are expected to occur in a warming climate, but cannot be reliably projected based on the CH2011 scenarios (Chapter 3). As a consequence, only the impact of average climate changes can be assessed, while great caution must be exercised where extreme events come into play. This general limitation is discussed further in Chapters 3 and 4.

Further limitations are inherent in the general approach of the CH2014-Impacts initiative, and need to be taken into account when interpreting the results. One limitation arises because the different impact studies, although based on the same data sets, are independent from each other. For example, the results of the glacier study (Chapter 5) are not directly incorporated in the study of river discharge (Chapter 6), which in turn is not part of the agricultural assessments (Chapter 9). Similarly, there is no coupling between the climate and impact modeling, which are treated as sequential stages. Additionally, each impact model has its own assumptions and specific restrictions. For these reasons, derived quantities cannot be expected to be fully consistent across the chapters of the report. However, an agreement between methodologically independent results is a measure of confidence and robustness, whereas inconsistencies or disagreement may indicate process complexity and intricacies that are at present not fully understood scientifically.

The number of impact models for such a comparison is still very limited owing to the national character of the CH2014-Impacts initiative. Finally, the comparability of different impact studies presented in this report is limited by the use of climate data beyond the CH2011 datasets in a few cases, and the incomplete exploration of the scenario cube by some of the impact models. These deviations are discussed in the corresponding chapters and the synthesis (Chapter 12).