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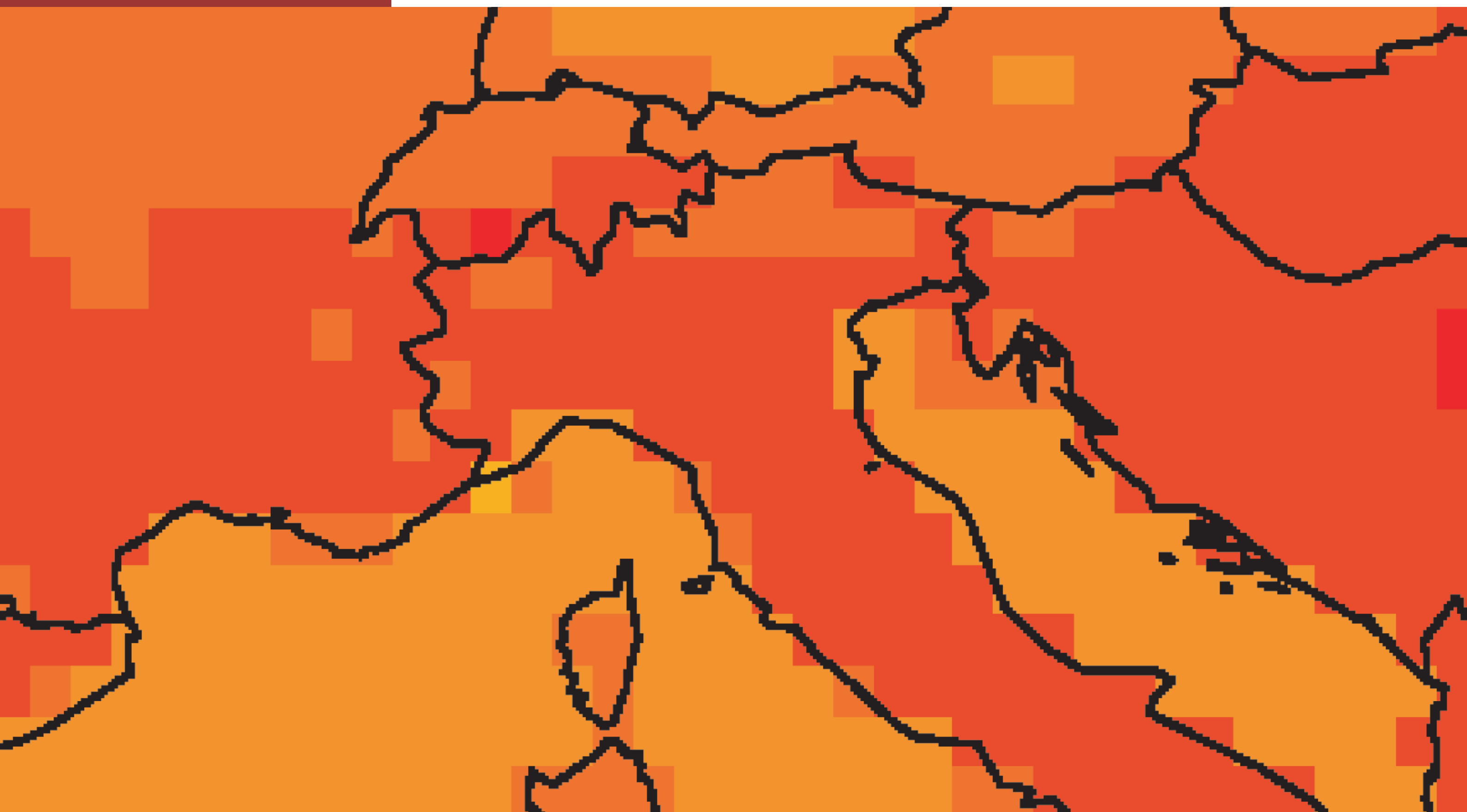
ProClim–
Forum for Climate and Global Change
Forum of the Swiss Academy of Sciences

Climate Change and Switzerland 2050

Expected Impacts on Environment, Society and Economy



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The Advisory Body on Climate Change (OcCC) has the mandate to formulate recommendations on questions regarding climate and global change for politicians and the federal administration. It was appointed established in 1996 by the Federal Department of Home Affairs and the Federal Department of the Environment, Transport, Energy and Communication (ETEC). The mandate to create this body was given assigned to the Swiss Academy of Sciences (SCNAT), which who invited approximately 30 persons people from research, the private sector and the federal administration to participate in this advisory body. The responsibility for the mandate on the part of the federal administration lies with the Federal Office for the Environment (FOEN). The Federal Office for the Environment (FOEN) provides federal representation.

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Cover picture
Section of a modelled temperature change map of from the CH2050 basics scenarios, Christoph Frei, MeteoSwiss, Zurich

Climate Change and Switzerland 2050

Expected Impacts on Environment, Society and Economy

Contents

Editorial

About 45 years ago, when I was a little girl, we children could go on wild sledge rides every winter on the Ackermannstrasse down the Zürichberg, just under the Central Meteorological Institute (MZA; MeteoSwiss today). In the meantime, a lot has changed. Sledge rides in Zurich, in the midlands and in the foothills of the Alps are hardly possible anymore. But also the increase in road traffic would make sledging on a neighbourhood street impossible.

And how will the near future look? What will our children be able to do in 45 years? What kind of Switzerland awaits them? The report "Climate change and Switzerland in 2050" (CH2050) deals with these questions. The IPCC (Intergovernmental Panel on Climate Change) 2001 and 2007 reports serve as the scientific basis. The research reports available today with their scientific data and facts prove what has been evident for years: With a probability of more than 90 per cent, the largest proportion of the observed increase in the global mean temperature since the mid-20th century is due to the increase in greenhouse gas concentration caused by anthropogenic emissions. Today, the evidence available cannot be ignored: Global warming is man-made. Climate change has become a problem of the 21st century for all people on Earth. The IPCC report calculates different scenarios up to 2100 and beyond – by then the measures taken today will show obvious effects on climate.

In our report CH2050, we want to focus on the halfway mark for now. What do climatic changes at the local level mean for Switzerland in the near future? What effects on the different natural landscapes and in the economic-social sectors of daily life will be noticeable? How can society and economy deal with the changes becoming apparent? What need for action is there in politics? What kind of measures must be taken in order to be successfully prepared for these challenges?

We need to ask ourselves these questions. It is the task of the Advisory Body on Climate Change (OcCC) to convey the scientific view to the economy, society and politics, and in this way to work out strategies and approaches for Switzerland. CH2050 should therefore serve as the basis for the desired and necessary future direction, in order to plan the required measures and shape political, economic and societal actions in Switzerland.

Dr. Kathy Riklin, National Council
President of the OcCC

Summary

This report describes possible impacts of climate change and vulnerabilities of the environment, economy and society in Switzerland due to the emission of greenhouse gases that are to be expected up to the year 2050. The potential impacts on various areas are discussed, as well as measures and strategies to adapt to the expected changes. Because global emissions reduction can only mitigate the situation in the long run, the expected global warming to 2050 will take place largely independently from such efforts. If greenhouse gas emissions are not reduced considerably within the coming decades, the consequences of warming may turn out to be much more severe in the second half of the century than those presented in this report.

The report assumes a warming of approximately 2 °C (with a range of uncertainty between 1 and 4 °C) in autumn, winter and spring, as well as just under 3 °C in summer (with a range of uncertainty between 1.5 and 5 °C). With regard to precipitation in winter, an increase of about 10% is expected, whereas in summer a decrease of about 20% can be assumed. The number of extreme precipitation events is very likely to increase and therefore also the number of floods and mudslides, particularly in winter but possibly also in summer, despite smaller total precipitation amounts. In summer, heat waves will generally increase, and probably droughts as well. In contrast, cold spells will decrease in winter.

In the future, in particular in the service sector, less heating energy will be required in winter and more cooling energy in summer. This will mean a shift in the energy demand from fuel to electricity. Newer buildings normally possess good heat insulation that reduces the heating demand during the cold season. However, dissipation of waste heat (produced by machines, people, etc.) is limited and requires cooling, in particular with increasing temperatures and heat waves in summer. Energy-efficient devices, air conditioning and sun screens, etc. may provide relief. Construction standards should be adjusted to the future climate. Relief measures are also possible in urban development, for instance, by creating aeration corridors.

The small runoff and decreasing cooling effect on rivers, in particular in summer, will have an adverse effect on hydropower and nuclear energy. Annual production is expected to decline by a few per cent by 2050.

New renewable energy will become more competitive due to higher energy demand, the demand for CO2-free energy and increasing energy prices. As measured by today's consumption, their share in the Swiss electricity supply may rise to over 10% (5500 GWh/year ≈ 20 PJ/year). The focus is primarily on energy gained from windmills and wood. If long-term trends and the development of the forestry and timber industries are considered, the potential of wood may triple. However, the emission of air pollutants related to energy production from wood would have to be reduced.

Climate change means an increasing risk of service interruptions in the energy sector. The emerging supply gap should be reduced as soon as possible, primarily by exploiting the energysaving potential and by promoting renewable energy. The dependency of Switzerland on foreign countries for its energy supply may thereby be reduced. The future energy production should remain as CO2-free as possible.

In comparison to other countries, Switzerland possesses substantial water reserves. Climate change will affect these reserves: Less water will be available in summer and autumn, and this will be more pronounced during drought periods. At the same time, the demand for irrigation in agriculture will increase, causing contention between ecosystems, different users and regions. This may lead to losses in agriculture and in electricity production, mainly in run-of-river power plants. Water supply, however, can probably be ensured by optimised water management.

Infrastructure value at exposed locations has increased considerably. Accordingly, the damage potential of floods, mudflows and landslides

has become much larger during the past 50 years. The growing frequency and intensity of heavy precipitation events further adds to the damage potential. As precipitation increasingly falls as rain instead of snow, floods become more frequent and more severe, particularly in winter. Possible measures include sustainable flood protection by renaturation and broadening of rivers, and limiting damage potential. Adequate management of lakes and the use of storage reservoirs as back-up mean a reduction and shift in fluctuation. The ecological consequences, however, are unknown.

As natural disasters become stronger and more frequent, insurers and reinsurers will be forced to raise premiums or to limit coverage in order to be able to pay in case of loss. Preventive measures, such as adaptation, and implementation of spatial planning and construction standards, will be necessary to make risks insurable again. Alpine regions are particularly under pressure to adapt the development of buildings and settlements, due to the threat posed by natural disasters and the dependency on winter tourism.

Possible consequences of climate change, in particular of extreme events, need to be included in risk modelling to estimate the damage potential of the insurance industry, as well as of any other branch of the economy. Currently, the insurance industry is developing new products to deal with a higher variability of more intense loss events. However, their market share is still very small in comparison to traditional insurance and reinsurance models.

Domestic tourist destinations, mainly at lakes and in the Alps, may become more attractive with increasingly hot summers. In winter, though, the rising snow line means that ski resorts in the foothills of the Alps may not operate profitably anymore. The expected higher number of tourists in summer will not compensate for the loss of income of mountain railways and the hotel sector in winter. Ski resorts situated at high elevations may possibly benefit. In these areas, pressure on the second-home market is to be expected. With the increasing threat to traffic routes from extreme events, the accessibility of tourist resorts in the Alps becomes more difficult. The attractiveness of alpine tourist areas will also be influenced by decreasing snow–reliability and expected changes in the natural scenery, in particular the retreat of glaciers. By 2050, smaller glaciers will probably have disappeared. Melting permafrost means a costly risk for a number of mountain railways, as at higher elevations the foundations of pylons and stations are often anchored in the frozen loose stone. The risk of rock slides increases as well.

In order to maintain the attractiveness of tourist destinations, offerings need to be adjusted to new conditions. It is essential to consider possible climatic and scenic changes in planning.

A moderate warming of less than 2 to 3 °C may have an overall positive effect on Swiss agriculture. The productivity of meadows and the potential crop yield of many cultivated plants will increase as a result of the longer vegetation period, provided that the supply of water and nutrients is sufficient. Livestock farming will profit from this as well. On the other hand, water supply will decrease in summer, weeds and insect attacks will occur more often and damage caused by extreme events will increase. Through the suitable choice of cultivated plants, cultivation methods and management, agriculture will be able to adapt to a moderate rise of 2 to 3 °C of the mean temperature by 2050. The increase in heat waves and drought periods is problematic. Furthermore, more frequent precipitation events will aggravate soil erosion. The demand for irrigation will increase in many regions. These risks may be reduced by diversification of farms and higher insurance cover.

If the temperature rises by more than 2 to 3 °C by 2050, the disadvantages will outweigh the advantages of warming: During the vegetation period, water scarcity will become more frequent, and faster plant development will result in harvest losses for crop and grain legumes. However, liberalisation of the markets and adaptations to agricultural policy will have a stronger impact in Switzerland up to 2050 than climate change.

As the heat wave summer 2003 showed, the increase in heat waves in Switzerland, in combination with an elevated ozone concentration, represents the most important health consequence of global warming. It is possible, though, to counter the increase in mortality caused by heat with adequate measures. Heat waves also impair the efficiency of the working population and thereby have economic effects. The likely increase of other extreme events such as floods, mudslides, and possibly also storms, causes death and casualties but also has severe psychological consequences.

With higher temperatures, the danger of food poisoning due to spoilt food increases. The development of various vector-borne illnesses is rather uncertain. However, in Switzerland, the spread of malaria or dengue fever is quite unlikely. On the other hand, West Nile fever is on the advance. Higher temperatures could also generate new vectors or cause a vector to change its host. With illnesses transmitted by ticks, there may be changes in the range of vectors, infection rates and period of activity.

In Switzerland, the species composition of ecosystems will change in the long run because different species react differently to climate change. Flora and fauna will continue to approximate those at lower elevations and in more southern areas. Heat-sensitive species will move to cooler areas at higher elevations. Less mobile species will be radically reduced or disappear.

The productivity of forests and agriculture, as well as the availability of clean water, may be affected by the combination of high temperatures and low precipitation. At higher elevations, the productivity of forests and permanent grassland will be somewhat enhanced by warming, at lower elevations it will be constrained by summer drought. In the future, water resources will also be of increasing importance to ecosystems, in particular to those situated in valleys and hill country.

From today's perspective, the expected consequences of climate change in Switzerland to 2050 seem manageable without severe societal problems, provided that warming does not exceed the expected magnitude. However, there are not yet any precise estimates of the costs for the adaptations and measures mentioned, which, for some areas, may be of economic relevance. In particular, the tourism sector will have to face drastic changes.

These conclusions should not hide the fact that long-term development in the second half of the 21st century crucially depends on emission reduction measures implemented within the next years and decades, and the consequences in case of a business-as-usual scenario would be much more severe. Moreover, there are many countries in the world, in particular developing countries, that on the one hand will be hit by more serious consequences and, on the other hand, will not posses the financial resources to adapt. The emerging geopolitical developments may well have consequences for Switzerland.

Introduction

This report discusses the effects of climate change on Switzerland to the year 2050. More than 100 experts from the most varied fields were involved. Their wide range of knowledge was collected, discussed and brought together in numerous workshops and meetings.

A regional climate scenario forms the basis of the report and is discussed in the Background chapter. Based on this, the report discusses the impacts of climate change on land ecosystems, agriculture, water management, health, the energy sector, tourism, buildings and infrastructure, urban Switzerland and insurance. These topics are not treated exhaustively; rather an attempt is made to estimate the climate-induced changes we can expect based on current knowledge, to assess their severity and to determine what kind of decisions must be taken in order to adapt to the changes.

The year 2050 was chosen because at that time, all the global climate scenarios proposed by the IPCC show a distinct warming but are still relatively close together. This allows us to discuss the effects of climate change without distinguishing between the different scenarios. Then again, many readers will live to see the effects of climate change described in this report. 2050 therefore has the advantage that we cannot shirk our responsibility and leave the solution of the problem to the next generation, as would be possible in the case of a long-term scenario for 2100.

In 2050, the effects of climate change will be superimposed by socio-economic and political changes that are almost impossible to estimate. In order to make clear the difficulties and uncertainties associated with this, it may suffice to think about how a person in the year 1950 would have pictured life in our country today. Many developments that have taken place within the past 50 years were not foreseeable – consider the progress in gene technology or the spread of computers. In spite of this difficulty, it is important to look ahead and to try to recognise important climatic changes in good time. Climate change is a very slow process, the negative effects of which will be discernible over many decades or even centuries. Forward-looking actions are in the interests of humankind.

The report shows that Switzerland is in a favourable situation in many areas and that the effects will still be relatively small by 2050. This should not lead us to take climate change lightly, since the year 2050 is only a short phase in a long-term development, which will speed up and bring about many, much greater changes. Moreover, many countries will be hit much harder by the consequences than Switzerland. The authors of this report are convinced that constraining greenhouse gas concentrations through systematic climate policy represents the simplest and most effective possibility to limit the damage and adaptation costs due to climate change nationally and abroad.

Finally, I would like to thank all the experts involved who contributed to this project as authors, workshop participants or reviewers, the collaborators of the ProClim and OcCC office, who carried out this project with a great deal of patience and input, and Markus Nauser, who raised the idea for this project over tea in Marrakesh during the COP 7.

Roland Hohmann

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Background

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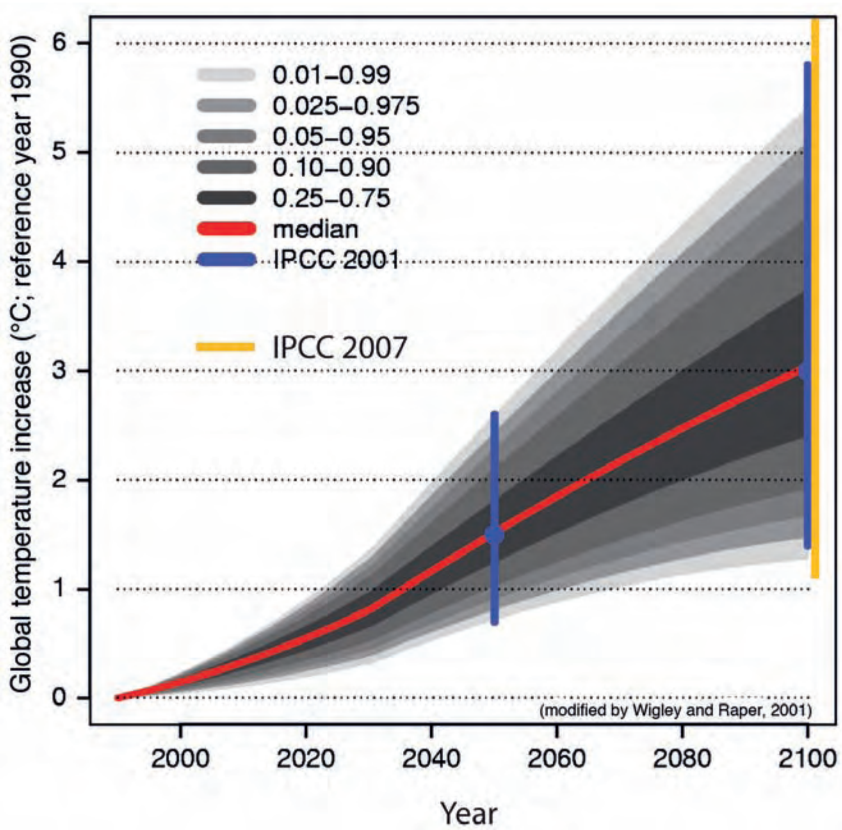

1. The future climate of Switzerland

Observed changes during the 20th century

During the 20th century, the mean global temperature increased by about 0.6 °C.[1] In Switzerland – like in other continental regions – the warming was stronger than the global average. In the 20th century, the temperature increase was about 1.6 °C in western Switzerland, about 1.3 °C in the German-speaking part of Switzerland and about 1 °C south of the Alps. North of the Alps, the frequency of abnormally warm months, that is, months with an average temperature more than 2 °C above the long-term mean, had already increased by about 70%.[2] The precipitation regime had changed as well. Annual rainfall increased by about 120 mm (8%) during the 20th century. In the northern and western part of the alpine area, mean winter precipitation increased by about 20 to 30%.[3] Heavy daily precipitation and heavy precipitation lasting between 2 to 5 days increased in autumn and winter in large parts of the midlands and the northern edge of the Alps.[4] Since evaporation rose in parallel to the warming by 105 mm (23%), the mean annual runoff remained virtually the same. At the same time, water reserves linked to glaciers decreased by about 50 cubic kilometres over 100 years. This decrease in the glacier volume contributed on average about 12 mm/a (1.2%) to the runoff.

Temperature and precipitation scenarios

In the future, climate change will accelerate. Depending on how greenhouse gas emissions develop, an increase of 0.8 to 2.4 °C in the global temperature by 2050 and 1.4 to 5.8 °C by the end of the 21st century compared to 1990 must be expected, unless drastic emission reduction measures are taken.[1,5] The water cycle will change as well (see fig. 4). However, climate change will not affect all regions in the same manner. How will the climate in Switzerland change in the future? Regional changes are distinctly more difficult to estimate because the respective surroundings (relief, distance from the sea, local wind patterns and their oscillations, etc.) have a significant impact. This report is based on a regional temperature and precipitation scenario for Switzerland.[6] The calculations of various combinations of global and regional climate models from the EU-project PRUDENCE[7] provided the basis for the calculations that enabled the uncertainties in the physical understanding of the climate system to be estimated.

In a second step, the dependency of the results on the future trend of emissions was taken into consideration. However, possible political measures to reduce greenhouse gas emissions (e.g.,

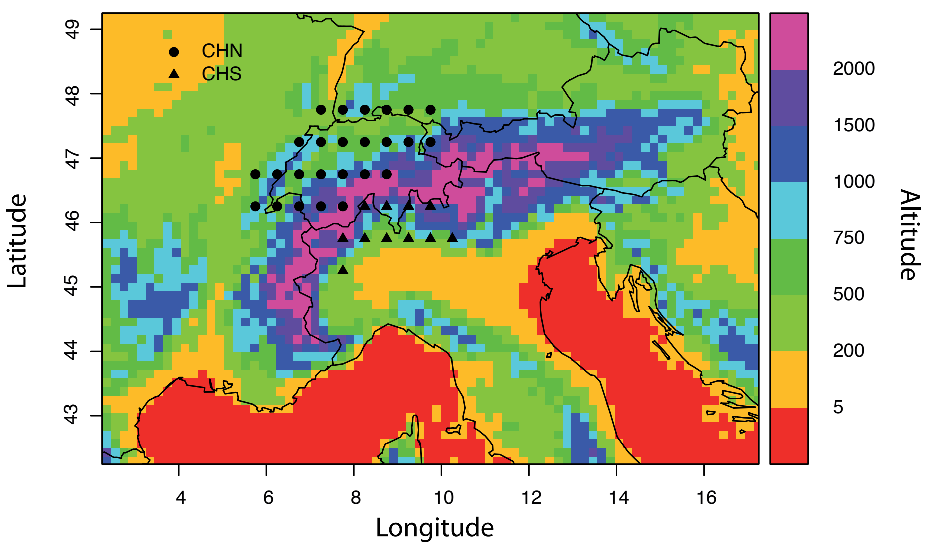

Figure 1: Representation of the grid points used for the analysis for northern (CHN) and southern (CHS) Switzerland, respectively. The topography (m a.s.l.) is shown in colour (resolution: 15 km).

the Kyoto Protocol and subsequent actions) were not included. Drastic actions to reduce emissions will not have a major impact before 2050 but will have an important influence on the development in the second half of the 21st century. The underlying data and statistical analyses are described in detail in Frei (2004)[6]. For this study, the mean values were calculated for the northern and the southern sides of the Alps (fig. 1) for the years 2030, 2050 and 2070.

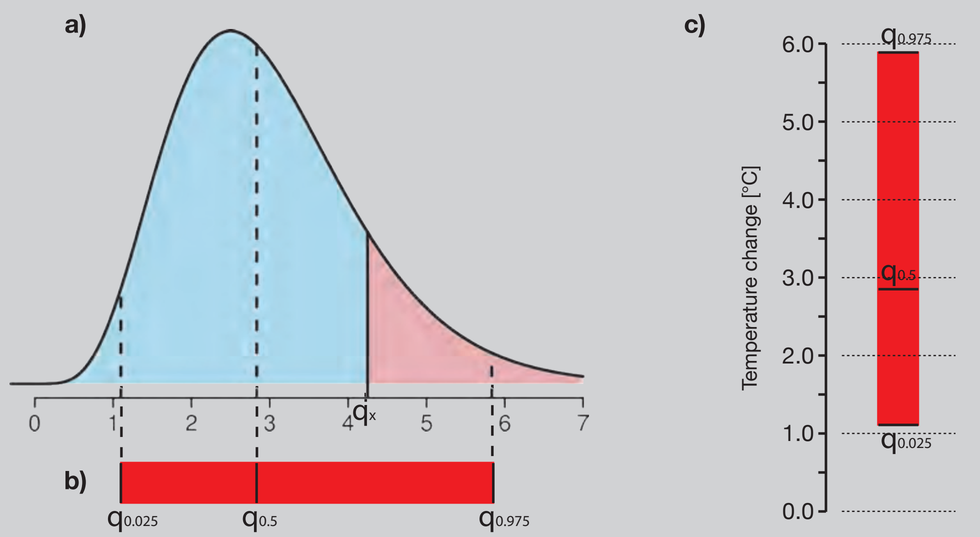

Figure 2: Schematic probability distribution using temperature change as an example (a). The distribution is characterised by the median ($q_{0.5}$) and the 95% confidence interval ($q_{0.025}$ to $q_{0.975}$) (b). In this report, the probabilistic scenarios are represented by these statistics (c).

Basis of calculation and presentation of results

The calculations from the EU project PRUDENCE served as the basis.[6] The uncertainties regarding the physical understanding (model uncertainties) were derived from the variance of the results of the 16 different model combinations for Europe. These combinations resulted from joining two medium IPCC emissions scenarios (SRES A2 and B2[7]), four different global climate models and eight different regional climate models in varying ways. The temperature values for the period 2071–2100 were scaled by means of a statistical method for the years 2030, 2050 and 2070.[6] Regarding the impact of the emission trend, the results on the regional scale were assumed to show a similar variance as the results on the global scale, based on the most important IPCC emission scenarios. The resulting uncertainties of the change may be represented as a probability distribution (fig. 2a). The value qx is the x% quantile and denotes the value of the change that will not be exceeded with a probability of x%. The median (i.e. the 50% quantile, $q_{0.5}$) divides the distribution into two areas of the same size and denotes the mean estimate of the change. The 95% confidence interval between the 2.5% and 97.5% quantile ($q_{0.025}$ to $q_{0.975}$) denotes the codomain within which future change will occur with a probability of 95%, according to the calculations above.

The calculated distribution may therefore be represented in a simplified way by means of the quantiles 2.5%, 50% and 97.5% (fig. 2b). This report shows the distributions for the different seasons side by side as vertical bars (fig. 2c).

The availability of further model results from a current EU research project (ENSEMBLES) is likely to further improve the calculations in the near future. New findings may either reduce or enlarge the area of uncertainty. The latter may happen if, for instance, new sources of uncertainties emerge due to the detection of processes that have been so far neglected.

CH2050 Scenarios

The calculated temperature and precipitation changes for the northern and southern sides of the Alps for the years 2030, 2050 and 2070 are represented in figures 3 and 4. They show the expected future trend and make it clear that Switzerland will increasingly be exposed to faster and stronger climatic changes. Particularly in the second half of the 21st century, the process may be influenced considerably by major emission reductions. Such measures are not taken into consideration in the development depicted. Due to the inertia of the climate system, the course is already set for the coming years and decades.

The results for the year 2050 are compiled in table 1. They form the basis of this report. Until 2050, the warming will be practically the same on the northern and southern sides of the Alps. According to a middle estimate (median, see box), the temperature will increase in northern Switzerland by 1.8 °C in winter and 2.7 °C in summer, and in southern Switzerland by 1.8 °C in winter and 2.8 °C in summer. For the transitional seasons, the warming will be comparable to the warming in winter (spring: 1.8 °C on the northern and southern sides of the Alps; autumn: 2.1 °C on the northern side, 2.2 °C on the southern side).

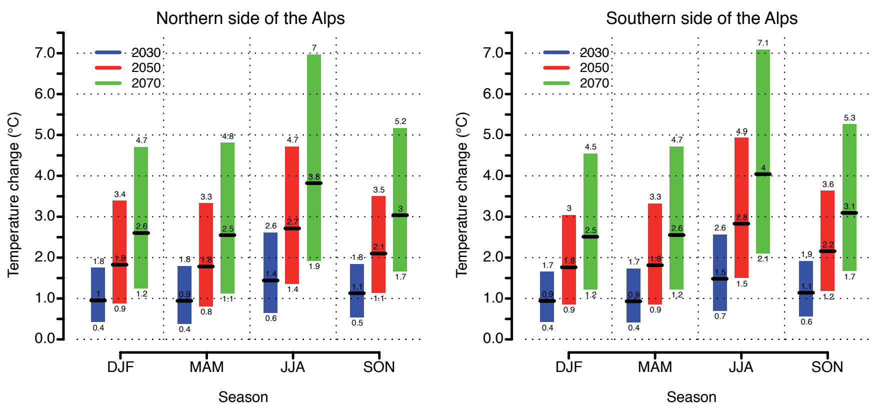

Figure 3: Change in the mean temperature in winter (DJF: December to February), spring (MAM: March to May), summer (JJA: June to August) and autumn (SON: September to November) on the northern and southern sides of the Alps in the year 2050 compared to 1990. The horizontal lines show the middle estimates (medians). There is a 95% probability that the warming will be within the coloured bars (95% confidence interval, see box).

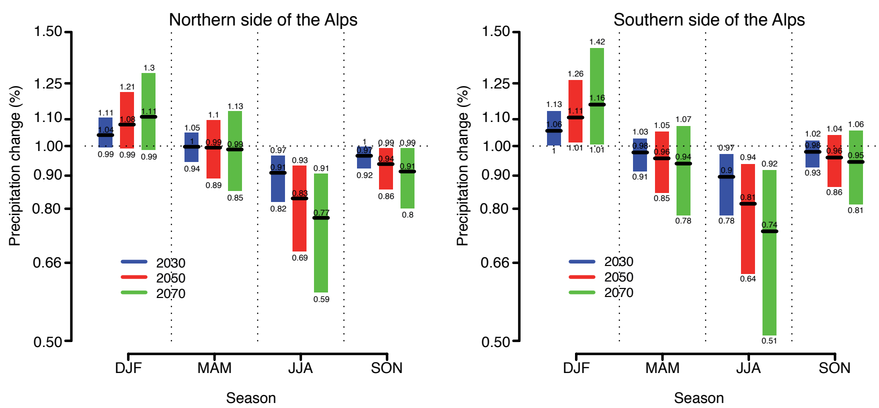

Figure 4: Relative change in the mean seasonal rainfall on the northern and southern sides of the Alps in the year 2050 compared to 1990 (logarithmic scale; for definition of seasons see fig. 3). A value of 0.50 indicates a decrease by 50%, a value of 1.25 an increase by 25% compared to today's conditions. The horizontal lines show the median. There is a 95% probability that the change in rainfall will be within the coloured bars (95% confidence interval, see box).

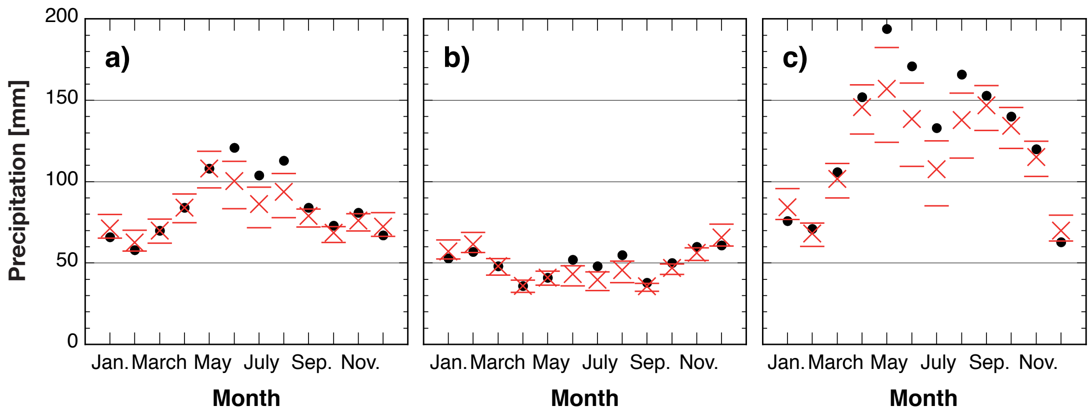

Figure 5: Monthly rainfall in a) Bern Liebefeld, b) Sion and c) Lugano today (black dots) and in 2050 (red; median and 95% confidence interval)

Table 1: Change in temperature (above) and in rainfall (below) in 2050 compared to 1990 (blue numbers: median; red numbers: 95% confidence interval). The 2050 scenario forms the basis of this report.

Region	Season	Probabilities		
		0.025	0.5	0.975
Northern Switzerland	Dec/Jan/Feb	0.9	1.8	3.4
	March/Apr/May	0.8	1.8	3.3
	June/July/Aug	1.4	2.7	4.7
	Sept/Oct/Nov	1.1	2.1	3.5
Southern Switzerland	Dec/Jan/Feb	0.9	1.8	3.1
	March/Apr/May	0.9	1.8	3.3
	June/July/Aug	1.5	2.8	4.9
	Sept/Oct/Nov	1.2	2.2	3.7

Region	Season	Probabilities		
		0.025	0.5	0.975
Northern Switzerland	Dec/Jan/Feb	-1%	+8%	+21%
	March/Apr/May	-11%	0%	+10%
	June/July/Aug	-31%	-17%	-7%
	Sept/Oct/Nov	-14%	-6%	-1%
Southern Switzerland	Dec/Jan/Feb	+1%	+11%	+26%
	March/Apr/May	-15%	-4%	+5%
	June/July/Aug	-36%	-19%	-6%
	Sept/Oct/Nov	-14%	-4%	+4%

The circumstances are also very similar for precipitation for the northern and southern sides of the Alps. The changes in the various regions differ in all seasons by only a few percent (fig. 4). On the northern side of the Alps, an increase of 8% is expected in winter (11% on the southern side) and a decrease of 17% in summer (19% on the southern side) by the middle of the 21st century. In spring and autumn, precipitation increases or decreases are possible. In summer, the area of uncertainty is particularly large.
The calculated absolute precipitation changes in Bern Liebefeld, Sion and Lugano are shown in figure 5. Generally, annual precipitation will decrease slightly (-50 mm in Bern Liebefeld, -20 mm in Sion, -150 mm in Lugano).

Assessment of changes

How can climate change be assessed? Will the climate in Bern in 2050 be like in Rome today? In order to answer this question, climate scenarios for different measuring stations of MeteoSwiss were compared to today's conditions. The comparison is complicated by the fact that temperatures and precipitation depend to a large extent on the topography, the geographical position and other local factors. For precipitation, the comparison of the stations does not result in a consistent picture and therefore makes little sense.
On the other hand, there are stations in Switzerland and abroad where today's temperature conditions match those that specific locations will experience in 2050 as a result of the warming. In a weak warming scenario, the temperatures in Zurich will resemble those of today's conditions in Sion, with medium warming they will be similar to today's conditions in Magadino, and with strong warming they will be similar to today's conditions in Torino (fig. 6). In a weak warming scenario, the temperature profile of Basel correlates well with today's profile of Grono, with medium warming with today's profile of Lugano, and with strong warming with today's profile of Verona.
However, with regard to such comparisons, one has to bear in mind that the problems of climate change are not primarily caused by the new climate state but rather by the process of change and the resulting problems of adaptation.

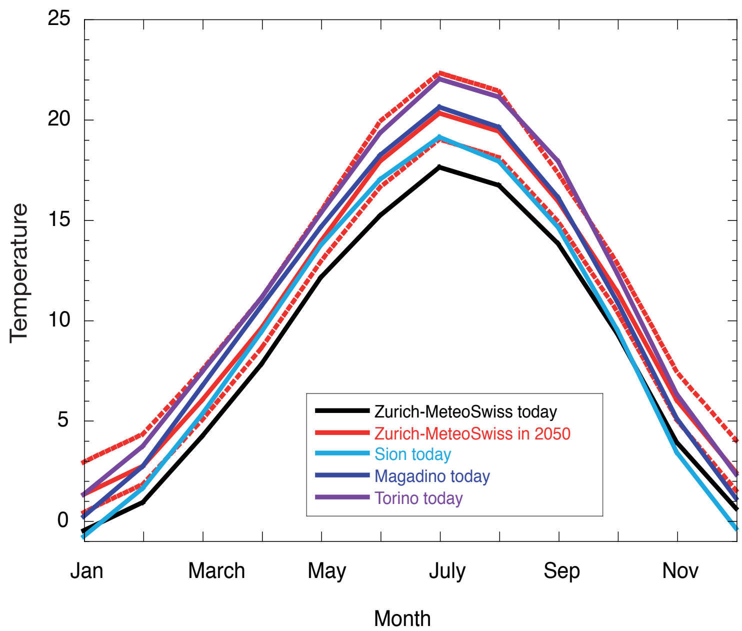

Figure 6: Comparison of MeteoSwiss temperature curves for Zurich today and in 2050, with today's temperatures in Sion, Magadino and Torino, according to weak, medium and strong warming scenarios.

2. Extreme events

Estimating the changes in extreme events is important with regard to many questions, for instance for the dimensioning of flood control structures. The climate scenario on which this study is based only makes statements about the seasonal means of temperature and precipitation and does not contain any information about the extremes. However, the changes in extreme events have been analysed in many studies. A compilation can be found in the OcCC report "Extreme Events and Climate Change".[8]
From our knowledge of the physics of meteorological processes and the climate system, it may be expected that certain extreme events will increase while others will decrease. The changes are likely to differ between regions. Today's climate models are only able to approximate the small-scale processes of extreme events. Scenarios of the trends of frequency and intensity of extreme events are therefore still very imprecise. Statistical statements about actual trends of extremes are also very difficult and only possible for a few categories of extreme events (see below).[9] The following compilation therefore discusses changes only if they are statistically significant with regard to past observations and/or if plausible evidence pointing to a trend in a certain direction exists.

Temperature extremes

Temperature extremes show the most distinct trend. With a rise in the mean summer temperature, hot spells with higher temperatures will occur (fig. 7).[2] According to climate models, the variability of mean summer temperatures will increase as well, which will also lead to more hot spells with higher temperatures.[2,10]
Climate models show a more significant increase in absolute maximum temperatures than in the mean daily maximum. According to this scenario, conditions like those of the 2003 summer heat wave will continue to occur very rarely in the case of weak warming, every few decades in the case of medium warming, and every few years in the case of strong warming (see section 3). The increase in extremely hot summers would occur even faster if, additionally, the variability of the summer climate increases, which most climate scenarios suggest as likely.
In contrast, the frequency of cold spells and the number of frost days will decline. In winter, the daily temperature variability will become smaller because minimum temperatures will rise more strongly than mean temperatures. This effect will be particularly pronounced in areas where the snow cover decreases as a result of the warming. The change in the risk of late frosts (frosts that occur after the beginning of the vegetation period) is uncertain since the vegetation period will shift with the warming as well.

Precipitation extremes

For Central Europe, new analyses show an increase in 1- to 5-day precipitation extremes in the winter half of the year.[11] The PRUDENCE models show that heavy precipitation events of a kind that occur only every 8 to 20 years nowadays, will on average occur every five years by the end of the century. The situation is less clear for the summer season. Although the models show a distinct decrease in the mean rainfall, the 5-yearly extreme value shows a slight increase.

Floods, landslides and debris flows

An increase in precipitation intensity and extremes harbours the potential for more frequent floods, landslides and mud slides. However, the actual effects on these natural hazards are also determined by other processes that are affected by climate change (soil moisture, snowmelt, runoff regime). Statements about the change of these natural hazards are therefore difficult (see Water management chapter).

Drought

In agreement with the decrease in mean rainfall and the number of rainy days, extremely dry periods will last longer and occur more frequently. The combination in decreasing rainfall and higher evaporation may result in a regional decrease of the soil water content. Furthermore, due to the decrease in snow reserves in the Alps, rivers that are fed by snowmelt in summer will more often dry up and the seasonal water sequestration in the Alps will diminish.

Storms

The frequency of storms in Central Europe will most likely decrease. At the same time, the frequency of very heavy storms (e.g., of the category of “Vivian or “Lothar”) may increase. Generally, the paths of cyclones and storms will shift polewards.

3. Basic estimate of other climatic variables

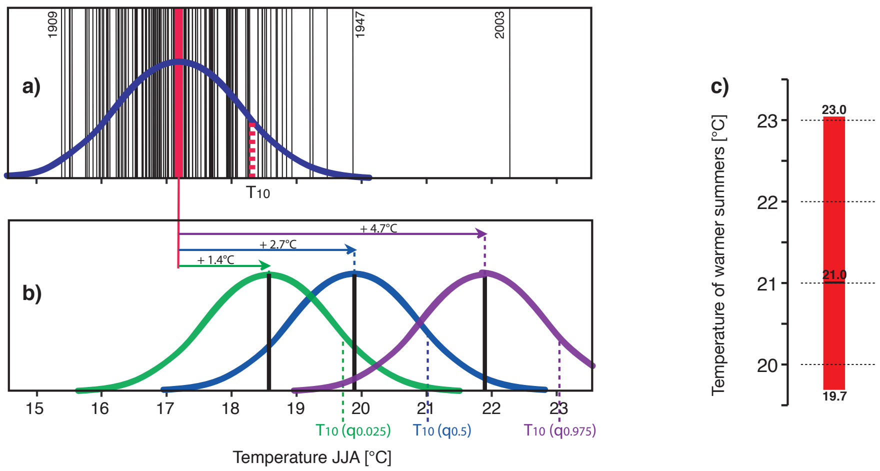

Figure 7:
a) Distribution of summer temperatures from 1864–2003, and b) in 2050.
c) The temperature of a 10-yearly hot summer also increases with climate change.

Based on the climate scenario here, basic estimates of changes in other climatic variables are possible. Following are some examples:

Hot summers

According to the climate scenario, warming will be particularly pronounced in summer. What does this mean for the temperature of hot summers?

Figure 7a shows the mean summer temperatures in the lowlands on the northern side of the Alps for the years 1964–2003. The corresponding probability distribution (blue curve) displays a mean value T_M = 17.2 °C (red line). A summer as hot as occurs on average only every ten years is warmer than T_{10} = 18.3 °C.

With climate change, the probability distribution of mean summer temperatures shifts by 2050 and the temperature of a 10-yearly hot summer increases. In 2050, every tenth summer will most probably be warmer than 21 °C. In the case of weak warming, every tenth summer will be warmer than 19.7 °C, and in the case of strong warming, warmer than 23 °C.

To simplify matters, this estimate is based on the assumption that climate change does not influence the shape of the distribution (year-to-year variability) of the summer temperatures. If the variability should increase as a result of climate change – as most climate models suggest[9,10] – the frequency of extremely hot summers would increase considerably faster and more strongly.

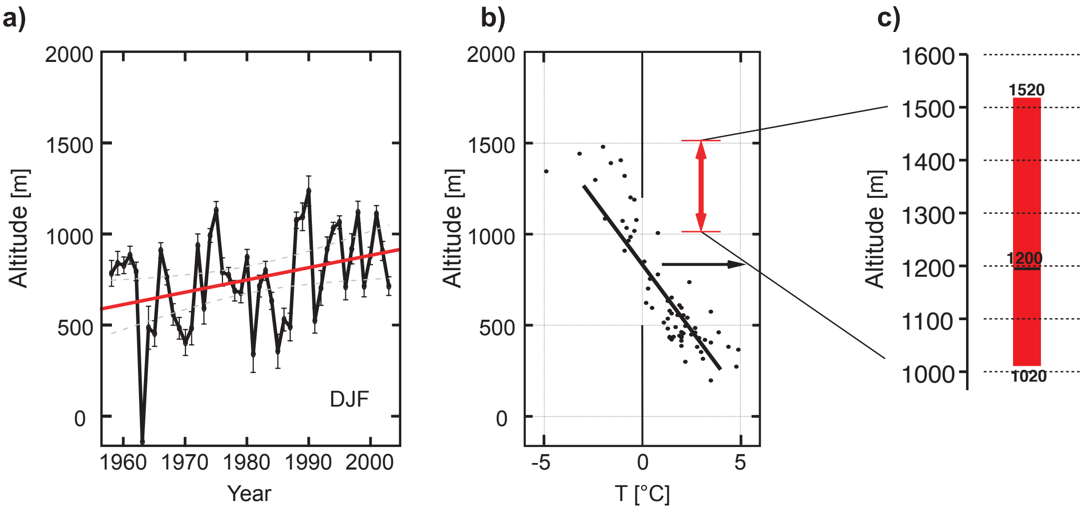

Figure 8: a) Change in the mean height of the zero degree line in the winter months (DJF) from 1958–2003. The calculation is based on 67 homogeneous ground temperature measurements. The red line shows the lineal trend, the dashed lines the corresponding uncertainty (95% confidence interval). b) Vertical distribution of average winter temperatures at MeteoSwiss measuring stations from 1959–1997. Today's zero degree line lies at ca. 840 m. a.s.l. c) By 2050, the zero degree line will have increased by ca. 360 m to 1300 m. a.s.l. (range 1020–1502 m. a.s.l.)

Zero degree line in winter

A temperature increase will result in a rise in the zero degree line in winter. This line roughly corresponds to the height of the snow line. Figure 8a shows the development of the snow line in winter for the period 1958 to 2003. In this period, the level rose from ca. 600 m in the 1960s to ca. 900 m in the 1990s (ca. 200 m per degree of warming).[12]

The vertical distribution of mean winter temperatures up to 1500 m a.s.l. is depicted in figure 8b (black dots). The regression line (black line) shows the average cooling with increasing height in winter. It cuts the 0 °C line at 840 m a.s.l., which corresponds to the mean height of the zero degree line during the observed period. If the observed rise (fig. 8a) continues in the future, the zero degree line will rise by about 360 m by 2050 in the case of medium warming (+1.8 °C in winter), by about 180 m in the case of moderate warming (+0.9 °C), and by 680 m in the case of strong warming (+3.4 °C) (fig. 8c).

Glacier retreat

The retreat of glaciers will be the most obvious change in the Alps as a result of climate change. Model calculations of the expected glacier retreat in relation to the reference period 1971–1990 are shown in figure 9.[13] They were calculated for a warming in summer between +1 and +5 °C and a change in annual rainfall between −20% and +30%.

According to the climate scenario here, by 2050, the area covered by alpine glaciers will have diminished by about three quarters in the case of medium warming (fig. 9b). In the case of a moderate warming, the loss in glacier area will be about 50% and in the case of strong warming about 90%. The relative losses will be smaller than the calculated average change for large glaciers and larger than the average for small glaciers. Many small glaciers may disappear.

Permafrost decline

The warming of permanently frozen ground in the high mountains is a slow process with long-term implications (see fig. 10). The warming described here will cause ice-rich rock faces in shady slopes between 2000 and 3000 m a.s.l. to melt, however, entire unfreezing will happen only here and there. The warming of the outer 50 meters of frozen rock faces, which has already occurred due to the temperature rise in the 20th century, will penetrate deeper and thereby cause thermal imbalance. In summit and ridge areas, such effects will be particu-

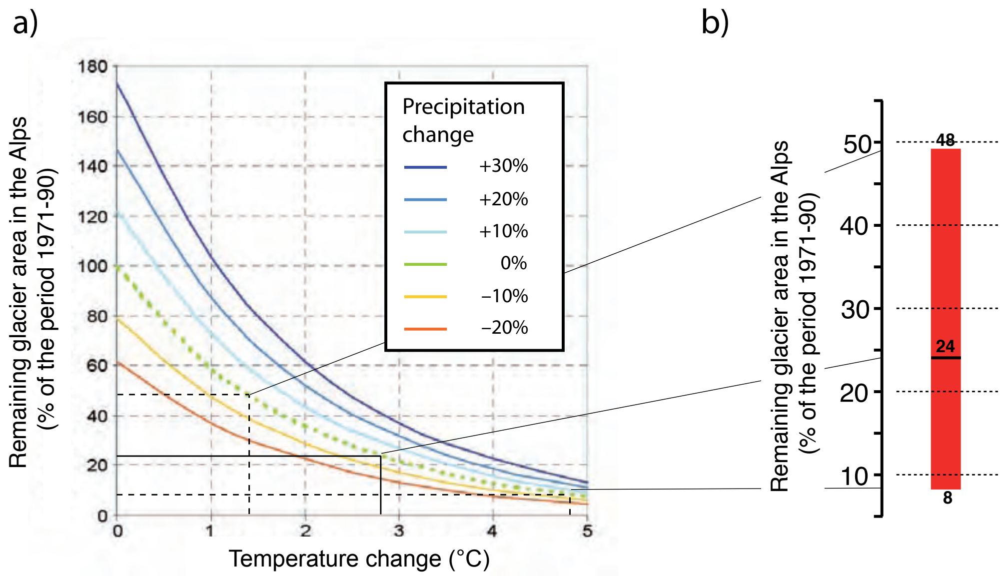

Figure 9: a) Change in alpine glaciation with an increase in summer temperature by 1 to 5 °C and a change in annual rainfall between –20% and +30%. b) According to this scenario, glaciation will decrease by about ¾ by 2050.

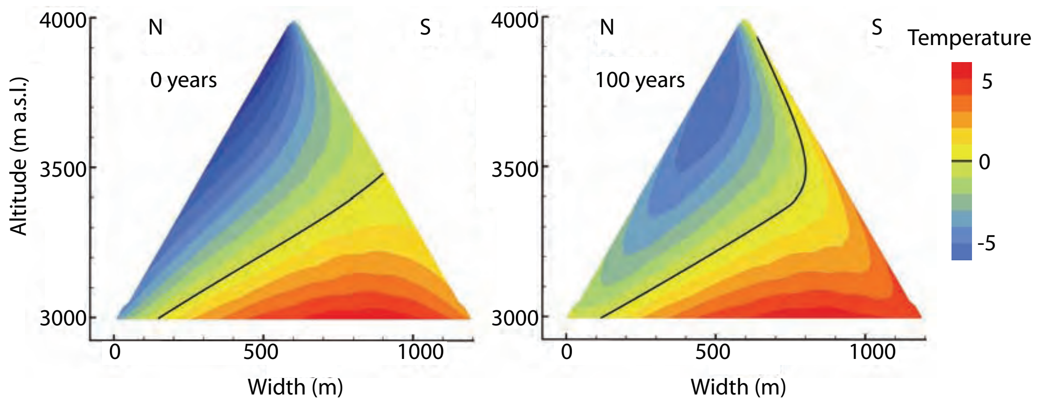

Figure 10: Warming of permafrost on an idealised summit (model calculation, thermal diffusion only).[14] Permafrost remains intact in the subsoil for a long time and can be present at places where the requisite climate conditions on the surface no longer exist. Heat penetrates from several sides into summits and ridges. As heat diffuses very slowly in the subsoil, this process takes place over centuries.

larly pronounced, since the heat can penetrate from several sides.

Rock slides

Since the mid-1980s there have been five major rock slides of more than 1 million m^3 in the Alps: Veltlin in 1987, Randa in 1991, Mont Blanc-Brenvaflanke in 1997, Thurwiserspitze/Ortler in 2004, and Eiger in 2006. The slide path sometimes reached far below the forest line (Veltlin, Randa, Mont Blanc) and all except Eiger affected tourism areas (roads, ski slopes, hiking trails). The relationship to glaciers and permafrost has been proven for three of these

cases (Mont Blanc, Ortler, Eiger), in the other two it is probable (Veltlin) or likely, but uncertain (Randa).
The stability of steep rock faces in the high mountains (especially above the forest line) depends primarily on the geological characteristics, the surface slope, the previous history and the ice conditions (glacier support, ice-filled network of fissures in permafrost). Every rock slide event has a specific combination of factors. However, currently, ice conditions are changing the most quickly and are therefore considerable codetermining factors. Critical conditions result in particular from the disappearance of valley glaciers (loss of support) and from warm permafrost (ca. 0 to −1 °C: mix of rock, ice and water). With increasing glacier retreat, progressive warming of previously cold permafrost faces and more deeply penetrating thermal disruption in frozen rock faces, as well as the frequency of rock slides and the probability of large-scale incidents are likely to rise.

4. Impact of climate change on the hydrological cycle

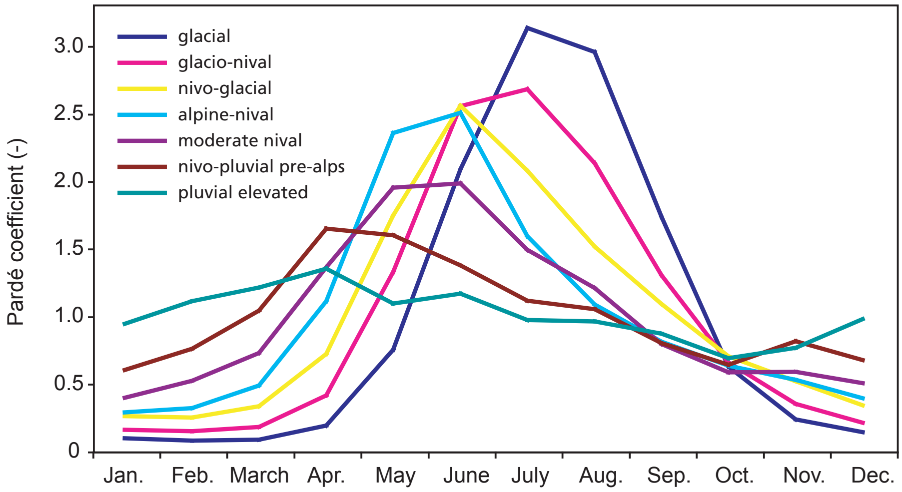

Figure 11: Mean runoff regimes of Swiss catchment areas at different altitudes. The spectrum runs from a regime mainly dependent on rainfall (pluvial, elevated, average height 800 m a.s.l.) to a regime mainly shaped by glaciers (glacial, 2700 m a.s.l.). The difference in height between the individual regimes averages 300 m. The Pardé coefficient describes the relationship between the mean monthly runoff and the mean annual runoff (glacial: shaped by glaciers; nival: shaped by snow; pluvial: shaped by rainfall).

Water resource systems – streams, rivers, small and large lakes, water in the subsoil, pores and crevices, groundwater and the large alpine water reservoirs like snow, firn and glaciers – are part of the hydrological cycle. It links atmosphere, soil, vegetation and bodies of water by evaporation and precipitation. The hydrological cycle is shaped by the climate and the actual weather, and conversely the hydrological cycle affects climate and weather – an extremely complex feedback loop. Humans interfere with this loop: Water is retained in storage lakes and reservoirs or redirected to other catchment areas, agricultural areas are extensively irrigated, wetland is drained and the groundwater level is raised or lowered.
Runoff is indirectly linked to precipitation. In the long term, with relatively steady evaporation,

the runoff follows the changes in precipitation. However, only a small part of the rainfall runs off directly; the larger part is stored, for instance in snow cover and glaciers, in the ground, in the groundwater, and in natural and artificial lakes. In the short term, runoff is influenced by the release of water from the stores.

Different runoff types, showing different annual runoff patterns can be distinguished by the degree of glaciation and snow cover. A selection of runoff types is depicted in figure 11. Watercourses that are mainly fed by melting glaciers and snow (glacial type) show larger runoff variations. The mean monthly runoff can easily vary between winter and summer by a factor of 30. Watercourses that are mainly dependent on rainfall (elevated pluvial type) show the least runoff variations.

The following changes can be expected by 2050 on the basis of the climate scenario presented here:

- Less precipitation falls as snow at lower and medium elevations due to warming. The snow line, which separates snow-covered areas from lower lying areas, rises by about 360 m in the case of medium warming (see section 3).

- The frequency and intensity of flooding will increase in winter in small and medium catchment areas of the midlands. This is due to the increased prevalence of rain instead of snow at lower and medium elevations, and the rise in heavy precipitation (see section 2).

- In the case of medium warming, glacier area in the Alps will decrease by about three quarters by 2050 (see section 3, fig. 9). This simple estimate is consistent with earlier studies[15], which showed a rise in the equilibrium line of glaciers by 400 m in the case of a warming of 2.7 °C in summer.

- Evaporation will generally increase as a result of warming. Due to soil dehydration, evaporation may be locally and temporally restricted and therefore reduced.

- As a result of the decrease in precipitation volume and the increase in evaporation, annual runoff will decrease, particularly in the south, but also in the north. This will happen in spite of the temporary contribution of meltwater from the retreating glaciers. In summer, soil moisture may be reduced for extensive periods of time (particularly in late summer and autumn in the south, but also in the north). In small and medium watercourses of the midlands and the south of Ticino, dry spells will occur more frequently. In addition, dry spells may occur more often in late summer in areas where glaciers have disappeared.

- Groundwater replenishment will decrease in summer and autumn in all non-glaciated areas.

- As a consequence of the changed accumulation and degradation of the snow cover, the rise of the snow line and the retreat of the glaciers, the runoff regimes (fig. 11) at a particular altitude will shift downwards by about one regime level.

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Land ecosystems

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1. Introduction

Background

What will the landscape look like in which our children and grandchildren live in 2050? What trends do we see today and how will our landscape and its productivity change if today's development continues at the current speed or even accelerates? This report represents, as is the case with any future projection, an estimate on the basis of current knowledge; an attempt to draw as plausible a picture as possible.

The most important impacts that ecosystems are exposed to nowadays include the following:

- Human-induced land-use changes
- Changes in the composition of the atmosphere (CO_2, nitrogen compounds)
- Climate changes (warming, changed precipitation patterns, storms)
- Accumulation of active agents (pesticides, hormones, general reactive substances)

The possible impacts of these changes are:

- Loss of biological diversity and entire biotic communities
- Change in land-cover types (forest, arable land, grassland, settlement, etc.)
- Loss of soil matter and soil quality
- Changed ecosystematic benefits to humans

Any assessment of the future development of the natural resources of a country necessarily begins by studying the current state and its historical development. In the case of land ecosystems (water-related systems are dealt with in the Water management chapter), the areal distribution of land-cover types over the course of time is the best starting point. Astonishingly, such data have only recently been available.

In Switzerland, the first vague estimates of forest area go back to the year 1840. Entire mountainsides were clear-cut at that time. The first Forest Act of 1876 restrained the rampant deforestation and brought about the preparation of the first forest inventories. Later on, the focus of interest was mainly on immediately required resources. Thus, during the World Wars, people were concerned with the potential of their own agricultural production and the suitable areas for this purpose. The methods used have also not been constant over time. It is, for instance, difficult to define what is and is not a forest. Are groves, windbreaks or emerging young-growth forests on former grassland included or not? The historical development of different land-cover types since 1900 is represented in figure 1 as an estimation based on historical data sources.

The first land-use statistics of Switzerland that were based on aerial photographs, and were therefore relatively precise, were made in the years 1979–1985. Further statistics exist from the years 1992–1997. A third update has been in progress since 2005 (conclusion by 2013). The changes between the first and the second land-use statistics are shown in Table 1.

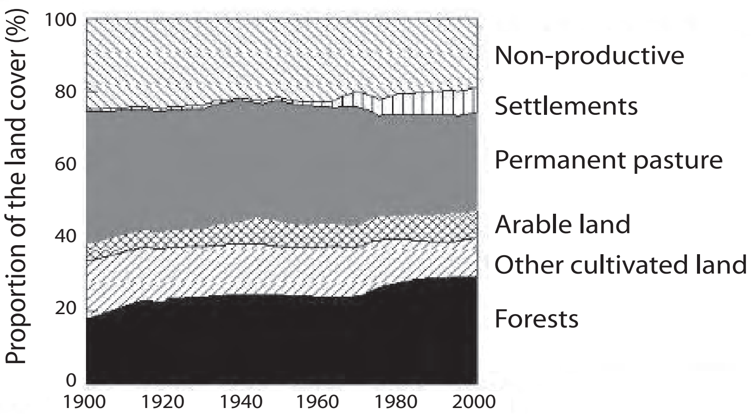

Figure 1: Estimate of the development of land-cover types in Switzerland between 1900 and 2000[1]

Table 1: Land-cover types in Switzerland. 74 basic categories were grouped into 4 main categories.

Land-use and structural categories	area in ha (% of total area)		changes between surveys	
	1979–1985	**1992–1997**	**ha**	**% (100%=1979/85)**
Settlement and traffic area	246'098 (5.97%)	278'772 (6.76%)	32'674	+13.3
Agricultural area	1’572’091 (38.15%)	1’523’930 (36.98%)	-48’161	-3.1
Forests and woods	1’252’815 (30.40%)	1’269’825 (30.81%)	17’010	+1.4
Non-productive areas and vegetation[a)]	1’050’044 (25.48%)	1’048’521 (25.45%)	-1’523	-0.1

[a)] Wetland habitats (inventory areas) are contained in this category (area sizes according to federal inventories for the protection of upland and low moors).

At the time of the first survey (1979–1985), agriculture, with 38.1%, accounted for the largest proportion of the about 41,290 km^2 of land area in Switzerland. The proportion of forest and other wood types amounted to 30.4% of the land area. Settlements, industry and transport networks covered just under 6% of the land area, 25.5% were so-called unproductive areas: rocks, glaciers, lakes and rivers. It can be roughly said that the forest and settlement areas have increased by about 1.2% within the 12 years (1992–1997) at the cost of agricultural area, although this trend has accelerated considerably in the recent past. In the second survey, forested areas covered about 31% of the land area. The strongest increase could be noted for shrub forests in the alpine region. The 3% loss of agricultural land seems small but hides the fact that cultivated land disappears on a large scale (3% corresponds to the disappearance of the entire canton of Obwalden).

Meadows and pastures have given way to forests at marginal yield locations and primarily to urbanisation in areas of high-yield agriculture. Urbanisation and traffic areas together increased by 13.3% in only 12 years. In this period, 7,5ha of agricultural land were transformed into settlement and traffic areas per day.

The following considerations and scenarios should be appreciated against this background. The significance of forest areas increases, that of grassland decreases, and glaciers retreat from large areas in high alpine areas. The development of the urban area and of agriculture is dealt with in separate chapters. Here, the Land ecosystems chapter focuses on:

- Forest ecosystems
- Meadows and pastures (extensively used grassland)
- Wetland habitats (moors, meadows, banks)

The impacts on fauna are presented as a topic covering all three land-cover types.

The historical developments that led to today’s state are briefly outlined in order to subsequently focus on the future. Emphasis will be put on the climate variables temperature and precipitation, and for each, continuous development and extreme events will be distinguished. The text is divided into the following sections:

- Biodiversity (species loss, habitat loss, biotic interactions)
- Natural hazards and living-space security (erosion, floods, slope instabilities)
- Ecosystem benefits and products (wood, food, carbon stores)

Overview

The species composition of the ecosystems in Switzerland will change in the long term, since the species react differently to climate change. Many of these changes are irreversible. On the one hand, hitherto existing species will disappear, on the other hand, foreign plant and animal species will immigrate from warmer regions. Thus, the Swiss flora and fauna will approximate even more closely that of lower-lying and more southern regions. Species bound to cooler living conditions will have to move to higher elevations in the alpine region. There, however, they will be strongly restricted in area due to the topography and in the extreme case may lose their habitat entirely. Species with little opportunity to spread out will be particularly affected by the warming. Climate change as well as land use will have an impact on biodiversity in the coming 50 years.

The resistibility of the vegetation and therefore the security of our living space can be strengthened by a broad diversity of species and sustainable use of the natural ecosystems. More frequent and more intense extreme events can severely disturb ecosystems locally so that they may lose their protective effects, at least in the short term. However, the mean changes calculated for 2050 will not substantially endanger living space security in Switzerland.

Land ecosystems not only fulfil important functions like protection against natural hazards but also provide economically relevant products such as wood, food and clean water. This benefit will be primarily affected in the future by combined effects, such as high temperatures in combination with low precipitation. The productivity of forests and permanent grassland will change considerably: At higher elevations, a higher productivity will dominate due to the warming, at lower elevations, it will suffer due to summer drought. A pronounced water shortage in summer in combination with high temperatures – as for instance in 2003 and in a milder form in July 2006 – will strongly limit productivity. In years with sufficient humidity, the warming may possibly prolong the growth period, although the genetically determined pattern of development of many crops, as well as of domestic flora, allows for little scope for change (<2 weeks).

Water availability will become even more important in the future than today, although valleys and hill country will be most affected. The management of land ecosystems will have to adapt to the changed environmental conditions. Thus, the significance of high-altitude areas as ecological buffer zones for livestock husbandry will increase.

Links to other topics

Water management

- Groundwater level, demand for irrigation water for permanent grassland
- Production losses due to water shortage

Agriculture

- Conflicts about water use, highly mechanised cultivation methods and possible increased use of fertiliser and pesticides
- Alpine region as a rediscovered area for cultivation

Energy

Quality of power station catchment area (slope stability, erosion)

Health

- Immigration of foreign species (neophytes) that can cause allergies and asthma (e.g. *Ambrosia artemisiifolia)*
- Calamities due to the increase in natural hazards

Tourism

Failure of protective measures in the alpine region

Insurance

Question about insurance cover in the case of failure of the protective function of land ecosystems due to extreme weather events (security of living space)

2. Biodiversity

In Switzerland, the living space is strongly shaped by altitudinal zonation, which has led to the formation of vegetation belts. With climate change, these belts will move upwards but the species composition within the belts will also change. Particularly at lower elevations, this will mean a loss of hitherto existing species and the immigration of up to now foreign plant and animal species from warmer regions.

Even though Switzerland, with a land area of 41,290 km^2, is relatively small and is not situated at the sea (which is why the diverse coastal zone flora and fauna is missing), the number of species is similar to many other, much larger European countries. The relatively high diversity of species is due to the considerable altitudinal gradient, the geological diversity, the richly structured cultivated land that has been farmed traditionally for a long time, and the large number of natural habitats.

The distinct vegetation belts in Switzerland represent a reaction of fauna and flora to altitudinal zonation. These altitudinal zones are shaped by their specific climate and the topography. While the topography will hardly change in the short term, the climatic zones will tend to move upwards with warming. Thus a new combination of topography and climate results. The question of shifting and changing vegetation belts is therefore important with regard to further changes.

Due to their relative size, *vertebrates* depend to a large extent on habitat use and structure, as well as to direct use by people (hunt, pest control, etc.). This will – as with invertebrates – largely conceal the impacts of climate change. In particular with regard to mobile animals (e.g. birds), it can be assumed that immigration from warmer regions will remain relevant in the long term. Furthermore, the already currently observed trend that bird species that were once migratory now overwinter in Switzerland will probably continue, as a result of the favourable climate.

Development up to today

Since the last ice age, species have always naturally immigrated from warmer regions into Switzerland. In settlement areas at lower elevations, immigration is faster due to human influences, while ecosystems at higher elevations change only slowly.

Already today, a large proportion of the fauna and flora of cities and waterbodies are foreign species. The immigration of foreign animal species can take place very quickly due to their mobility. With regard to vertebrates, humans almost always play a major role. The spread of foreign species either happens on purpose or unintentionally due to the transport of goods.

The fact that the dominating forest belts in particular will move upwards with general warming is undisputed[2] and can be verified for the late and post-glacial development.[3] It is assumed that this shift could take a long time and that today's tree species distribution will have centuries to adapt to the changed conditions. The small number of observed species shifts in the range of the tree line, point to the fact that such reactions take place particularly slowly at high elevations.[4]

In Switzerland, the number of species has increased since the ice age as a result of the constant immigration of foreign species. Due to warming and the increasing mobility of people, this trend will even accelerate (fig. 2). However, new species rarely or with long lag times intrude into the present domestic vegetation and can mainly be found in disturbed habitats.

Domestic species increasingly become extinct for different reasons. Either they cannot tolerate the warming anymore, they are displaced by newcomers or suppressed by more strongly dominating domestic species. The latter is true for instance for forests, where the growth of most tree species has accelerated in the past 200 years with simultaneous decrease in use (fig. 3). This has led to denser plant stands and therefore to a decrease of sun-loving species. A similar development could be observed in the wetlands at medium elevations, which hardly change with decreasing precipitation but do react to increasing nutrient input.

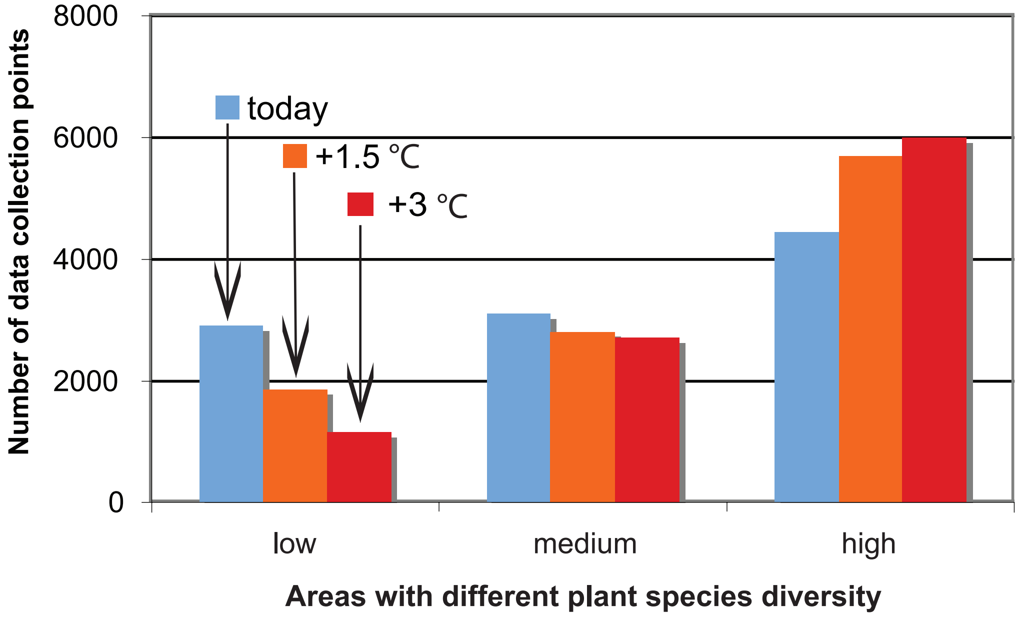

Figure 2: Projected changes in the number of plant species in Swiss forests due to climate change (simulation study, simplified).[5] With increasing temperature and simultaneous slight increase in precipitation (+15% in the model; according to current OcCC projections, precipitation will decrease), the number of species-poor areas will decrease, the number of species-rich areas will increase. The data collection points are random samples collected in the forest area at the intersection points of a 1-km grid mapped over Switzerland. The number of species relates to an area of 200 m^2.

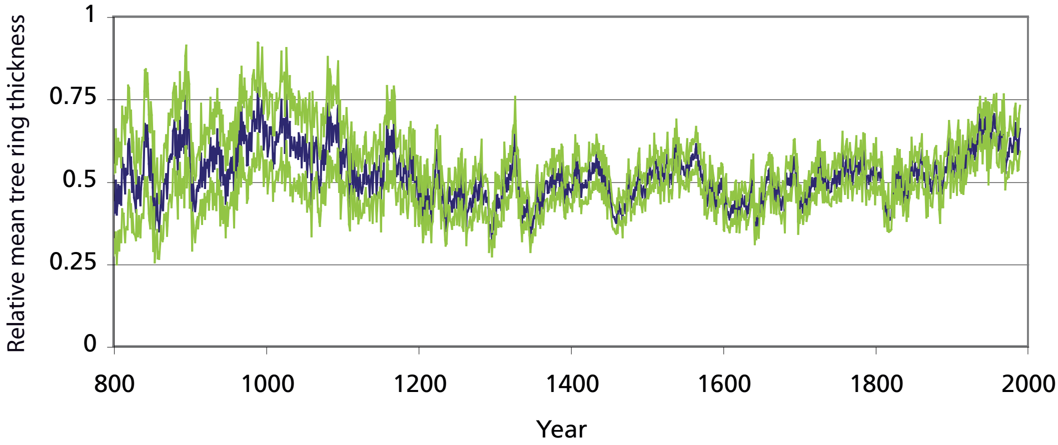

Figure 3: Average increase in thickness of the naturally occurring tree species in the alpine region up to 1993.[6] Since 1816, the tree ring width has steadily increased. The strong fluctuations (uncertainties) before the year 1200, are attributed to the lack of such old wood samples (low replication). Violet line: mean values. Green line: standard deviations.

Future

Climate change as well as land use will affect biodiversity in the coming 50 years. In general, the fauna and flora will increasingly approach that of regions at lower elevations and situated more to the south. It is difficult to estimate how many species will be lost or newly immigrate.

The immigration of foreign species into Switzerland will drastically accelerate in the coming 50 years due to the rapid temperature increase. Due to climate change, flora and fauna will even more strongly approach that of lower elevated and more southerly regions. In addition, animal and plant species (so-called neozoa and neophytes) from all over the world reach Switzerland due to trade (e.g. ornamental plants) and the mobility of the population. Many newly immigrated species do not at first have any enemies or illnesses and tend to population explosions.

Based on today's knowledge, not only the climate but also primarily the change in land use will strongly affect biodiversity. Utilisation will likely concentrate on favourable locations in valleys (agriculture) and well-accessible forests, due to the liberalised agriculture and forestry policy. Increasing energy prices could reverse this trend due to energy wood use. Many cultural relicts (e.g. structural elements in the landscape) of past centuries will disappear. In the Alps and the Jura, agriculture should be able to survive with the aid of direct payments, especially in important tourism regions. There will also be a gradual shift from today's propagated multifunctionality of the forest area to a subdivision of areas according to their respective prioritised forest functions: subsidised care for protection forests and specific forest reserves, forests without commercial use of wood, as well as managed forests, in which a profitable use of wood is possible. A further expansion of settlement areas and an increase in traffic can be anticipated, which will mean the loss of near-natural areas, as well as the further fragmentation of the landscape. The habitats of animals and plants will thus become smaller or disappear.

Figure 4: Since the 80s, *Mantis religiosa* has immigrated into Switzerland from the southwest (Jura) and Alsace. In the summer of 2006, egg masses were found in a forest clearing in Fricktal (Canton Aargau).
(Source: Peter Duelli, WSL)

As the time until the year 2050 is very short for most ecosystems, the general warming trend will lead to a inevitable uncoupling of “climate requirements” and actual habitat climate. This will lead to a gradual shift in the species pattern of the existing flora and fauna. Certain species will be stimulated, others will be repressed. These processes are superimposed on current land-use changes, such as the retreat of agriculture and forestry from mountainous areas An additional factor affecting these processes lies in historical changes in land utilisation. The consequences of these changes are only noticeable today, although they took place 100 years ago (e.g. age structure of forests, abandonment of wood pasture, increase in game population).

In the alpine region, species bound to cooler living conditions will be displaced to higher elevations. There, however, they will have a smaller total area at their disposal due to topographic reasons. Thus, the vegetation belts will not only move upwards but will also become restricted in area,[2] though different species competition may change this trend (slow down or accelerate), in particular for trees. Plant species carried by rivers and streams will immigrate the most quickly, namely in the warmest regions (waterbodies in Ticino, Rhine at Basel, Rhone at Geneva). However, the spread to higher elevations will be restricted by the delayed adaptation of the species to the climate. In the mountains, primarily pioneer species on virgin soils will be able to quickly follow the trend. Heat-loving neophytes will also spread in forests, which means that garden plants available in stores may spread over large areas in the Ticino and the midlands.

In Switzerland, except for the southern part, a decrease in the number of species is particularly expected in low moors. This will become even stronger if precipitation decreases and the extension of these habitats decreases due to water shortage. With regard to this process, the upland moors in Switzerland are in a special position. The higher temperatures and the longer dry periods endanger the moss cover and enable species uncommon in upland moors to invade these habitats. This is unwanted because it represents an ecosystem modification and species poverty represents a typical characteristic of upland moors. The displaced species are specialists that are unable to settle in any other habitat.

Warming will above all exert pressure on those species that are less mobile or depend on less mobile species as food or host. Mobile species can move to cooler habitats, which is simpler in the mountains than in the lowlands. Nevertheless, warming and land-use change will mean the extinction of many species, particularly in the Alps and in the Jura. Especially endangered are species with very isolated occurrences (endemites) and those that cannot move further upwards.

Cold-loving species inhabiting the tundra (mountain hare, snow grouse) will, for the present, find a larger habitat on mountains with a large alpine and nival zone, thanks to the spread of the vegetation cover but will become extinct on small, lower lying rocky outcrops. Cliff-dwelling species of southern origin (ibex, wallcreeper) will expand their habitats upwards or have already done so (rock partridge) (see fig. 5).

Also with vertebrates, the mobile forms (birds, large mammals) will be able to react more quickly to climate change. However, any upward shift of the habitat means a net loss of area, since the land area decreases with height. Reliable data in this regard are available for the population

Figure 5: Cold-loving species inhabiting the tundra, such as the mountain hare will, for the present, find a larger habitat in mountains with a large alpine and nival zone thanks to the spread of the vegetation cover. However, they will become extinct on small, lower lying rocky outcrops at lower elevations. (Source: Martin Merker)
Cliff-dwelling species of southern origin, such as the ibex, will expand their habitats upwards or have already done so, provided the mountains are high enough. Otherwise, the local populations might collapse. (Source: Thomas Jucker)

change of birds. As figure 6 shows, in the past 15 years, a decrease in the number of species on cultivated land but an increase in forests could be observed. This trend goes in the same direction as the spatial development of land-cover types. (fig. 1, table 1). For all organism groups, it is true to say that short-term, spectacular changes are less likely, and that these changes are restricted to single species. This is shown, for instance, in fig. 6 by the “Swiss Bird Index” of all bird species, which remains practically constant.

Overall, the number of species in Switzerland is increasing steadily in spite of increasing loss of species, since immigrations are considerably more numerous than cases of extinction. However, in the overall evaluation, the losses have to be given more weight because many of these species are becoming entirely extinct, that is worldwide, while the immigrating species often have their main distribution area in the Mediterranean, sometimes even on other continents.[7]

The shift from integrative land use (everywhere a bit of everything) to regional segregation (protection of species here, intensive production there) that is emerging in politics is equally important for the changes in biodiversity in Switzerland. This shift is scientifically and politically controversial, and signifies a change in society’s perspective regarding this problem.

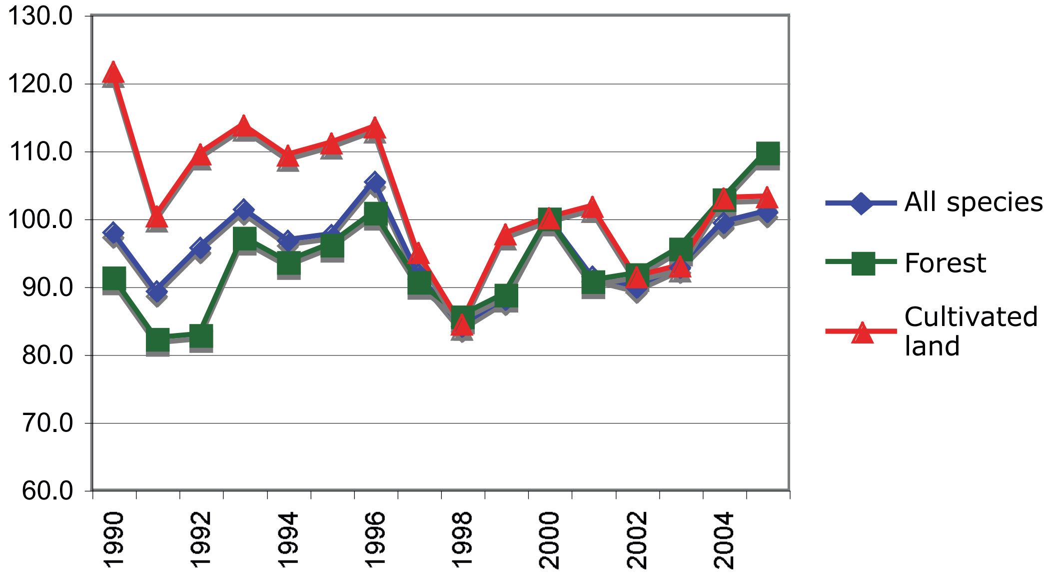

Figure 6: Development of the “Swiss Bird Index” (the SBI represents the number of sedentary bird species in different landscape types) over the past 15 years. In cultivated land, variety is decreasing, in forests increasing, and overall constant, if all bird species are considered. (Source: © Swiss ornithological station Sempach)

Measures

Direct measures for the preservation of endangered species are difficult to achieve. The best protection is offered by maintaining the habitat, which also includes the maintenance of small-scale, diversified land use.

The traditional measures for species and habitat protection for preserving species diversity are also quite suited to counteracting future developments. What is desirable is to have various types of land use side by side as well as a comprehensive system of species protection (including reserves) and specific species maintenance, depending on region and cultural characteristics.

The strong intensification of land use (agriculture, settlement and commercial) caused massive species losses in the last century that were not compensated for by partial extensification (mostly reforestation). Counteracting such losses is also worthwhile and a priority in relation to climate change. The situation presented by newly immigrating species is more difficult. Among these, there will be species that are harmless and whose spread is the logical consequence of the changed environmental conditions. Others, such as aggressive neophytes, neozoa and new pathogens, which endanger biodiversity, have to be systematically regulated. Recognising such species at an early stage is difficult and an area for ecological research.

3. Natural hazards and living space security

With increasing frequency and intensity of extreme events, ecosystems in Switzerland may locally be strongly disturbed and therefore lose their protective function, at least in the short term. The mean changes in climate to 2050 that are expected based on climate models will have comparably less effect on ecosystems. The risk to living space security and the integrity of ecosystems mainly results from climatic extreme events and the unadapted use of sensitive landscape types (e.g. non-native species composition of forest and changed use of mountain pastures but also introduction of pollutants into unused ecosystems).

The different landscape types and habitats in the mountainous area of Switzerland fulfil a multiplicity of important functions: Every kind of closed vegetation cover protects the soil, stabilises slopes and protects against erosion. Forests play a particular role in protection against avalanches and rockfall, and enhance the ecosystematic water storage. At the same time, vegetation is a provider of resources, and serves as a place for recreation and sport. These important functions are inseparably linked to the resilience, stability and dynamic adaptability of ecosystems, in particular of forests. Thereby, apparently unimportant organisms play a role in ensuring living space security. The interaction between these countless components ultimately determines the vulnerability of the systems to changes in use or climate. The use of ecosystems for agricultural and forestry operations but also for tourism has a much larger potential to change the protective functions within the time frame of a few decades than the future mean changes in temperature and precipitation. An accumulation of extreme climatic events can cause rapid changes in natural ecosystems and thus carries the risk of an at least temporary loss of functionality. In addition, the increasingly dense use of the landscape by humans leaves less and less room for major natural hazards (e.g. floods), which is why they are becoming appreciably stronger and are therefore also causing more damage.

Development up to today

Up to now, temporary losses of living space security have mainly occurred due to extreme events and settlement activity in hazard zones. However, the continuous change in the type of land use and the input of nutrients and pollutants from the air have made some ecosystems more vulnerable to further climatic disturbances. On the other hand, single changes, such as the increase in forest area, also show positive effects: Forests stabilise steep slopes much better than all other ecosystem types.

In Switzerland, forests and extensively used grasslands have undergone a great change in the past 150 years. In the past, every patch of land was assessed from the perspective of its productive benefit to humans. Thus, wetlands were drained, forests were oriented towards increasing the yield of qualitatively first-class wood, and meadows and pastures were also cultivated in rough terrain. In doing so, the issue of ecosystem integrity and also of the living space security linked to this was of secondary importance for a long time.

Today, many of these areas are not economically interesting anymore. However, the significance of intact vegetation cover for living space security has increased at many locations. This is because it is currently at many of these locations that the tourist infrastructure and settlement area profit from protection forest (both have advanced into potential hazard zones). Mountain pastures become overgrown (are lost as special living space and resources) and rough terrain is not used anymore. On the other hand, the pressure of the leisure society increases on almost all vegetation types.

These human influences have, in addition to climatic changes, affected the vegetation and in this way also the protective function against natural hazards linked to it. More forest usually increases the water storage capacity of the soil, improves slope stability and protects against erosion. Depending on the topography, more forest also protects from avalanches or rockfall. Running counter to this is the increase in extreme events, partly leading to floods and landslides, which could not be absorbed by the natural buffer effect of the vegetation. The increased incidence of storm damage has temporarily, strongly reduced the living space security in the areas concerned (e.g. the Vivian, 1990 and Lothar, 1999 storms). A greater weakening of the ecosystems due to extreme events has often occurred at locations where the topographic conditions had already required larger human interferences anyway in order to make modern human life possible, e.g. in alpine valleys or in the vicinity of rivers. To some extent, heavy precipitation has also occurred in combination with geological conditions that exceeded the retention capacity of any vegetation type. Extreme precipitation events led to the sliding off of entire forest sections (e.g. in central Switzerland in the summer of 2005).

However, temporary reductions in living space security have also occurred in forests where dryness, in combination with high summer temperatures and intensified insect attack, led to the extensive dying of trees (e.g. bark beetle epidemic after Lothar and in the dry summer of 2003, pine forests in the Valais;[8] see figs. 7 and 8). Also here, in addition to climatic influences, the type of forest utilisation in the last 100 years may have played a role. Deciduous trees, most notably the downy oak, quickly settle released areas and were therefore largely able to replace the function of pines up to now (see fig. 8).

Figure 7: The combination of enhanced winter windthrow and warmer summers results in a bark beetle population explosion. (Source: Christoph Ritz)

Figure 8:
At lower elevations in the Valais, the combination of abandoned land use (wood pasture) and warmer, drier summers leads to the rapid modification of pine forests into downy oak forests. (Source: Roman Zweifel)

Looking ahead

Further locally and temporally limited loss of protective functions of ecosystems is to be expected due to the predicted increase in the frequency of extreme events. This does not represent a problem for unused parts of the near-natural landscape far from urban areas, since new niches for plants and animals are generated by this dynamic. However, if settlement and transport networks are affected, these changes have disastrous effects.

50 years is a short time period for vegetation and in particular for forests because changes appear with some inertia and delay. Up to the year 2050, the mean (!) predicted climate changes hardly represent a substantial danger for the protective functions of vegetation cover and the living space security linked to this in Switzerland. However, more frequent or pronounced extreme events (heat, drought, fire, heavy precipitation, storms) can have massive effects locally and can abruptly change ecosystem integrity (such as after a forest fire or a heavy insect attack). Such processes will become more likely the more rapidly the climate changes and the more strongly vegetation is already in a process of change as a result of the general climate trend.[9] However, such scenarios of a sudden build-up of harmful effects (e.g. insect calamity as a result of drought) are hard to predict.
The effects of climate changes (in combination with human influences) for which there are empirical data can be estimated more reliably. Based on today's knowledge, stronger than average effects of climate change are to be expected for the following ecosystems by 2050:[10]

- ecosystems that are far from their natural form, composition and functionality due to human interference, e.g. forest monocultures with non-native species or over-cultivated (e.g. over-fertilised and thus species-poor) grassland
- ecosystems that are situated in climatic border zones, e.g. in melting permafrost areas, at arid sites on the border of desertification, at only slightly wet wetlands and in the vicinity of the upper timber line
- ecosystems in which land use has counteracted the natural climate-induced development of the past decades (e.g. at locations where

the upper timber line was kept artificially low by mountain pastures, the forest may advance again very quickly in the case of a reduction in use and simultaneously rising temperatures)

- ecosystems in which climatic changes trigger cascade effects, e.g. heavy attacks by insects or other pests due to higher temperatures (such as three instead of two bark beetle generations per season)

Measures, uncertainties, knowledge gaps

Varied species composition and sustainable use increase the resistance and stability of natural ecosystems, and best ensure human living space. Climate change can be influenced only slowly. However, we can change the way we use our living space more quickly. In so doing, we can also much more rapidly achieve a sustainable effect in order to maintain the protective functions of ecosystems.

In particular in the last 50 years, the settlement area in Switzerland has extended into topographically dangerous areas. Slopes that used to be forested, have been built on after forestry operations ceased. River valleys that were avoided for centuries, are intensely inhabited today. It is the vegetation (changed by humans) in particularly these exposed areas that is often no longer able to fulfil its protective function in the case of extreme events. Not only has global development brought with it anthropogenic climate change but it has also made people, in particular in mountainous areas like Switzerland, more dependent on living space security, which depends on intact vegetation cover. Technical measures will not be able to ensure living space security in Swiss mountain valleys without the assistance of natural ecosystems, especially of forests on steep slopes. It will therefore be crucial to promote varied species composition of ecosystems appropriate to the location and to create near-natural age structure and tree-species composition in forests where this no longer exists. Whether this diversification can take place rapidly enough, is, however, rather doubtful in view of the slow developmental rate, particularly of forest ecosystems.

Awareness must be raised (politically) of the direct link between near-natural (that is, well adapted and diverse), resistant ecosystems and living space security in mountain areas. In this case, recognising that ecosystems always include the people living in them and that sustainable development can only be achieved in consideration of human activities is particularly important in a densely populated country like Switzerland.

4. Use and products of ecosystems

Land ecosystems not only fulfil important functions such as living space security, they also provide economically relevant products like wood, food and clean water.

In addition to the comprehensive benefit of securing living space already described in section 3 on natural hazards and living space security, land ecosystems also fulfil important functions outside intensive agriculture, such as air and water purification, carbon and water storage, and nutrient recycling. They provide economically relevant products like wood, food and water. Furthermore, forests have a particularly high carbon sink potential due to the large biomass stock of trees; distinctly larger than that of grassland or fields (where the potential is consumed by humus). Although all these services and products are influenced by physical-chemical and climatic conditions, they have also been shaped substantially by land use for millennia.

Development up to today

In the past 100 years, most land ecosystems have been influenced more strongly by changes in land use than by climate change. Nevertheless, the effects of climate change on the supply of bioresources (e.g. hay, stock of wood, carbon storage) can already be observed in Switzerland.

The land use of agricultural and forest ecosystems has changed strongly in the past 100 years. Intensification and mechanisation in agriculture have above all increased productivity considerably but have at the same time reduced humus and thereby carbon storage in agricultural soils.[11] The stock of wood in Swiss forests has substantially increased in the last decades and is at a maximum today, both per unit of area (minor use) as well as due to the increase in forest area. About 5 million m^3 of wood is cut per year in Switzerland, although 7 million m^3 of wood could be used, based on the annual growth, without any negative effects on forest stands. In the past 50 years, forests have also grown much faster than before as a result of increased atmospheric nitrogen inputs and favourable climate conditions. Today, 90% of the Swiss forests are oversupplied with nitrogen, which, apart from enhanced tree growth, leads to a decrease in base saturation in the soil, soil acidification and contamination of the leakage water that feeds the groundwater.

Impacts of climate change can already be recognised today in the earlier budding and thus in the extension of the vegetation period by 5–6 days.[12] In the recent past, extreme events have occurred more frequently (e.g. the Vivian and Lothar storms, heat wave summers, major fires in the Valais) and have caused damage to forests.

The changes in use have taken a very different course depending on elevation. Whereas in valley sites in the past 10–15 years, extensification in addition to agricultural intensification has occurred, at the sub-alpine and alpine sites, extensification (conversion of meadows to pastures) dominates to the point of abandoning use entirely. These formerly cultivated areas become overgrown and forest moves in. If grazing is lacking above the mountain forest, more water than in the past is transferred into the atmosphere, due to evaporation and particularly transpiration of the now taller vegetation. Less water runs off (up to 10%), which can ultimately lead to reduced energy production in the catchment area of a hydroelectric power plant.[13]

Wetlands have been strongly changed by humans in the past 100 years.[14] Whereas in the past, they used to be significant water and carbon stores, many of them have been utilised for energy and agricultural production through peat cutting and drainage. As a result, wetlands in Switzerland have decreased in area by almost 90% in the last 100 years – associated with a large decrease in biodiversity and hydrological buffer areas.

Looking ahead

In the future, the functions and benefits of land ecosystems will be mainly influenced by a combination of effects, e.g. high temperatures combined with low precipitation. Water availability and the alpine region will be of particular relevance.

The climate scenarios for Switzerland in 2050 are within a range that will lead to perceptible changes in the productivity of forests and permanent grassland. The previous trend towards higher productivity due to intensification will be weakened or limited by a pronounced water shortage in summer at high temperatures – such as in the year 2003. Ciais et al.[15] showed that in Europe in 2003, the carbon sink completely changed and European forests turned from carbon sinks into clear carbon sources. This can result in reduced carbon storage in soils, enhanced by the possible increase in decomposition of organic matter in humus[16] and the decrease in carbon inputs by the vegetation. Should – as models predict – such dry summers become more frequent, carbon storage in wood and soil would decrease in the long term. However, local effects strongly depend on what happens to soil moisture. Carbon storage will continue to increase due to the expansion and underusage of forest stands, as long as rising energy costs do not effect a return to wood as a resource. Increased tree growth due to higher CO_2 concentrations is rather unlikely, since the supply of other essential nutrients (except for nitrogen) will not increase.[17] Water shortage in summer and autumn will mainly affect vale and hill country in the future. Water shortage will have less impact in high montane forests and at alpine elevations. Here, an increase in productivity is more likely. Water availability will thus become even more important in the future.

The cultivation of land ecosystems will have to adapt to changed environmental conditions (e.g. earlier hay harvest, irrigation of permanent grassland, adjustment of livestock, increased significance of high altitude areas for summer pasture, changes in the choice of tree species). Cultivation of higher altitudes to sustain livestock will likely become more lucrative again. That means that the alpine region will possibly become more important again as a rediscovered cultivation area as well as a retreat/replacement living space. However, this will only succeed if these areas are kept open by active management and the encroachment of meadows and pastures is stopped.

Uncertainties, measures

Adaptive forest and permanent grassland management is required in order to reduce or avoid the negative impacts of climatic changes on the benefits and products of these ecosystems. Alpine pasture land should be kept open.

The natural variety of tree species should be fostered as a protection against climate change or the consequences of extreme events. Extensive clearing should be avoided and old forest stands should be changed into multi-layered forests (e.g. "Plenterwald" – uneven-aged selection forest[18]) in order to ensure stability and guarantee that the stored carbon is not released into the atmosphere as CO_2.

Active management of the landscape, in particular in the alpine region, should include value-added aspects. The benefit can thereby be assessed for the entire society (also monetarily).

Political discussion must take place on how adequate sustainable management can/should be implemented and supported.

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18 Type of management as a result of which trees of any size and age can grow next to each other in small areas and can be used individually without damaging the forest structure.

Agriculture

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1. Introduction

Background

In Switzerland, land used for agriculture amounts to 37% of the total area. About one third of the agricultural land is located in the midlands. Pastures and meadows account for the largest part of the entire agricultural land (permanent pasture in fig. 1). Accordingly, the majority of the 65,866 farms focuses on livestock husbandry, whereby dairy cattle farming dominates. The most important land-use category in arable farming is cereals.

More than 70% of the farms are full-time enterprises. In 2003, the mean farm size was 16.2 ha. Plant products account for 47% of the output value of agricultural goods, dairy products for 27% and other animal products for 26%. In Swiss agriculture, the degree of self sufficiency is highest for proteins, with 70 to 80%, and lowest for carbohydrates, with 50 to 60%.

Agricultural policy in Switzerland is reforming agriculture step by step. Current agricultural

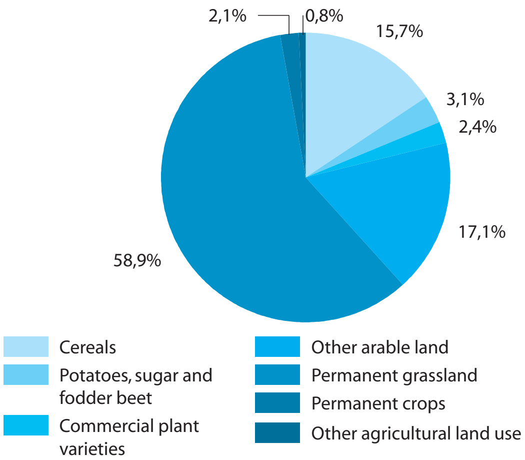

Figure 1: The most important land use categories 2003[1]

policy (AP 2007) focuses on the improvement of the competitiveness of domestic agriculture and food industries. In the next phase (AP 2011), this new focus will be further developed. These measures have a strong impact on the agricultural output value. Implementation of the expected commitments to the WTO will result in a reduction of the agricultural output value by about 1.5–2.5 billion Swiss Francs compared to the reference years 2001/2003.[2] Due to this development, the structure of Swiss agriculture will change considerably. At the moment, it is not possible to predict the consequences for land use, crop cultivation, or farming of grass and pasture lands. This uncertainty makes it difficult to quantify the consequences of climate change, that is, the direct consequences for agricultural production in Switzerland as well as the indirect consequences due to climate change in other countries (see section 9). The following considerations largely ignore such possible changes, which are caused by political and economic forces, and which may be of much more importance in the 2020–2050 time frame than the impact of climate change.[3]

Climate is one of the most important limiting factors for the cultivation and yield of crops and livestock husbandry. Due to the climate in Switzerland, arable farming is limited to lower elevations, whereas fodder production covers a climatically much wider variety of elevations and dominates at higher elevations. Climate change will therefore bring about a change in an important parameter. The following remarks focus on this expected change with regard to cultivation and yield per unit of area, suitability of location and pest management, as well as possible consequences and adaptabilities of cultivation measures, livestock husbandry and farm management. A closer examination of regions and cultivation methods (e.g., conventional or organic farming) is omitted due to the lack of data.

Overview

No threshold value for global warming can be given for the effect on agriculture. However, a moderate warming of less than 2–3 °C of the annual mean by 2050 will tend to have a generally positive effect on agriculture in Switzerland. The potential annual production of pastures will increase as a result of the longer vegetation period. The potential yield of many cultivated crops will increase as well given sufficient water and nutrients. Animal production will profit from cheaper fodder due to increased yield and from the longer grazing period. Negative effects will be related to the decrease in available water due to an increase in evaporation from plants and ground (evapotranspiration) with the decrease in summer precipitation, the increased prevalence of weeds and pests, and the increase

in climate variability and extreme events. In the case of a stronger warming of more than 2–3 °C by 2050, the disadvantages will prevail: Water shortage will occur more often due to the increase in evapotranspiration and decrease in precipitation during the vegetation period, and the accelerated plant growth of cereals and grain legumes will cause yield loss.
By taking measures involving the choice of crops, cultivation methods and farm management, agriculture will be able to adapt to a moderate increase in the mean temperature of 2–3 °C by 2050. However, the expected increase in weather variability and extreme events will be more problematic. Due to the increase in heat waves and dry spells, critical soil water conditions and droughts will occur more often in summer and the need for irrigation will rise in many places. It will be important to use the available irrigation water as effectively as possible. Conversely, an increase in heavy precipitation could intensify soil erosion. All in all, the risk of damage for special and arable crops and of yield loss in fodder production will increase. Yield security will be affected. Suitable general measures such as plant breeding and variety evaluation will play a role in mitigating the negative effects. The diversification of farms may be a useful strategy to reduce risk. In addition, the demand for insurance against yield loss due to extreme weather conditions will rise. International agricultural markets will play an important role in the future global and national food supply. In Switzerland, the liberalisation of markets and adaptations in agricultural policy will be more important influencing factors than climate change.

Links to other topics

Insurance
Demand for insurance against yield losses due to extreme weather conditions

Water management
Groundwater level; need for irrigation water; production losses due to lack of irrigation

Land ecosystems
Conflicts over water usage; highly mechanised cultivation methods and possibly increased use of fertiliser and plant protection products; immigration of foreign species (neophytes)

Health
Neophytes (e.g., Ambrosia artemisiifolia) that may cause allergies or asthma

Energy
Increased demand for energy due to irrigation systems

Tourism
Decreasing attractiveness of the landscape for tourists due to scrub and forest encroachment (particularly with a change in mountain agriculture)

2. Domestic plant production

A moderate climate change of less than 2 to 3 °C of the annual mean will have a positive effect on agriculture in Switzerland in many respects. The potential annual yield of pasture will increase due to the longer vegetation period. Provided that the nutrient and water supply is sufficient, the potential yield from arable farming and fodder production will increase for many crops. In the event of a strong warming, however, the disadvantages will prevail. A strong increase in evaporation from plants and soils, as well as a change in precipitation, could result in water shortage at many locations.

In the past, domestic plant production mainly depended on the suitability of the location, which is determined by the climate, soil characteristics and relief. Weather characteristics determined the course of cultivation to a large extent.

The climate change of the past years has already had a demonstrable impact on plant production. In the case of arable crops, the impact of temperature on sowing and harvest time is well documented. Today, wheat is harvested almost one month earlier than in 1970, which is partly the result of the introduction of early varieties, and the grazing of mountain pastures starts 15 days earlier than 30 years ago because mountain pastures become snow-free earlier.[4] The change in plant development mainly depends on the increase in temperature, in particular budding, blooming and ripeness of fruit in spring and summer. The phenological autumn phases do not correlate clearly with weather variables. Higher temperatures in winter and spring bring about an earlier start of the growing season, e.g., for dandelions. Trend analyses for the period 1951–2000 have shown that on average plants bloom 21 days earlier, foliation takes place 15 days earlier and leaves change colour 9 days earlier, while the falling of leaves takes place 3 days later.[5]

This trend will continue with future warming. Depending on the region, the vegetation period will be extended by about 7 to 10 days per decade,[4] which will result in an increase in the potential annual production of pastures.[3] With the decreasing number of frost days, the risk of frost damage decreases as well, although in the case of an early start of the growing season, the danger of late frost damage persists.

A moderate climate warming of less than 2 to 3 °C of the annual mean will have a positive effect on agriculture in many cases. Model calculations of potential trends in crop yield (including cereals) show that Central Europe will tend to be in a favourable zone until 2050. Provided that all soil nutrients are sufficiently available, an increase in the atmospheric CO_2 concentration, in combination with slightly higher temperatures and sufficient rainfall, means an increase in the potential yield of many agricultural crops. The yield increase caused by CO_2 is, however, minor in comparison to long-term cultivation effects, and the positive effect on yield will be weakened by more strongly rising temperatures.[6] At the same time, a higher CO_2 concentration reduces the protein content of wheat grains, which results in a reduction of the baking quality of the flour. A slight decrease in rainfall in spring and summer will also have a positive effect on farming at many locations. The number of field workdays will increase and the decrease in soil water content will favour the use of bigger agricultural machines. In summer, periods with 2 to 3 consecutive dry days are beneficial to fodder production because insufficient drying impairs the quality of hay and aftermath.

In the case of a stronger warming of more than 2 to 3 °C of the annual mean, the negative effects will prevail. A stronger warming means accelerated plant development, which will result in yield losses for today's common varieties, in particular for cereals and grain legumes.[6] Rising temperatures increase the potential evaporation from plants and the soil surface. Depending on air humidity, soil moisture, short-wave radiation and the condition of the vegetation, the effective evaporation and therefore the current water consumption of crops, will also increase. Model calculations show a considerable reduction in the mean soil moisture during the vegetation period.[7] In view of the projected changes in seasonal precipitation patterns (more precipitation during winter and less during summer), water shortage could become much more frequent during the cultivation period at many locations (see fig. 5).

Uncertainties

It is uncertain to what extent a change in the regional differentiation of local conditions (climatic suitability) will develop, with a change in favourable and unfavourable locations, and to what extent the change will mean advantages of location within Switzerland and also internationally.

3. Extreme weather events

Climate change will mean a change in the probability of extreme events. The expected increase in heat waves and heavy precipitation events will increase the risk of damage for special and arable crops, profit cuts in fodder production and enhanced soil erosion.

Extreme weather events like drought, hail or heavy precipitation are of particular importance to agriculture. Hail damage for fruit, vine and vegetable cultures used to be the most common weather-related risk. After 1730, summers with drought occurred about every 50 years.[8] Difficulties arose particularly when two dry periods followed each other (preceding winter or summer), like for instance in 1947.

Climate change will mean an increase in the risk of extreme events and the corresponding consequences for agriculture.[9] Heat wave summers of the magnitude of summer 2003 will become more frequent[10] (see Extreme events section in the Background chapter) and the probability of drought damage will increase in the midlands and Jura. On the other hand, heavy precipitation will increase in the winter months, leading to damage of winter crops and increased soil erosion. No predictions are possible yet for hail.[8]

The magnitude of damage caused by extreme events is larger than the usual annual fluctuations in profit. Insurance solutions to cover the associated property damage exist. What is lacking is insurance coverage for yield loss due to extreme events like drought. How can the losses of drought years be absorbed? 2003 showed that governmental measures (e.g., a reduction in customs tariffs) can help. However, what will happen if drought years become more frequent?[11]

Uncertainties

Given the presented trend, the question of insurance cover for damage in animal farming and fodder production, and of financing damage redress as a result of heavy precipitation, hail and drought also becomes increasingly pressing. The question of whether agriculture itself, governmental or other sources will cover the costs involved remains open.

Figure 2: Corn field showing drought damage 2003 (Source: Liebegg, U. Voegeli)

4. Yield security

Climate change affects yield security. Suitable general measures, such as plant breeding and variety evaluation, can contribute to maintaining yield security in the future. In fodder production, the earlier start of the vegetation period could mean increased yield security.

In agricultural plant production, the conditions influencing yield typically change irregularly. Regional fluctuations in yield are caused by the epidemic spread of disease causing organisms or pests, or by stress resulting from extreme weather events. When the magnitude is too great, this can be an economic problem not only for single farms but also for the entire agriculture of a country. Since the end of the 1960s, fluctuations in yield could be reduced for arable farming and fodder production thanks to the introduction of new means and methods of production, as well as the continual variety change. In Switzerland, this decrease is noticeable for pasture yield and wheat, and slightly less apparent for potatoes (fig. 3). Future yield security will be influenced by climate change. The increase in extreme weather events will have a negative effect (see section 3). Plant breeding and variety evaluation are key measures for maintaining yield stability and reducing the use of production factors (pesticides, water, fertiliser, etc.). The future range of varieties will also need to include varieties that have lower yields but are more drought resistant or robust. The earlier start of the vegetation period will mean an increase in yield security for fodder production, since the first cut can already be made in spring.

Uncertainties

It is not clear to what extent the progress in breeding and selection will be able to keep up with the trends in extreme weather events.

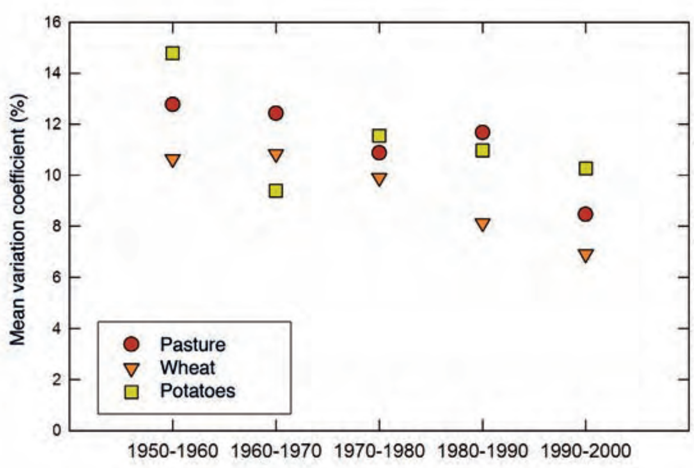

Figure 3:
Temporal trend of yield stability for pasture, wheat and potatoes in Switzerland (moving average of the variation coefficient for 10-year cultivation periods). The negative trend between 1950 and 2000 shows an increasing yield stability.
(Data source: Swiss Farmers' Union)

5. Water supply and location

Critical soil water conditions and summer drought could become more frequent in Switzerland in the future. This would require irrigation at many locations. The extent of local water shortages not only depends on the water requirement of crops but also on local conditions.

The water requirement of many crops (cereals, legumes, root crops, oilseed) that are grown in Switzerland today is relatively high, at 400–700 mm for the growth period.[12] Productivity losses occur if the water available in the soil is less than 30–50% of the useable field capacity for a longer period of time.[13] Optimal growth can then only be attained if the crops are irrigated.

With today's precipitation volume, the need for continuous or area-wide irrigation is small. In the midlands, about 600 mm of rain falls on average between April and September (with an annual variability of 100 mm), which corresponds to a mean soil water content of about 60% of the useable field capacity. Since 1900, less than 500 mm have been measured only 15 times, less than 400 mm only five times. Total precipitation in the sub-alpine and alpine zones is larger; only the inner-alpine valleys, in particular the Valais, are confronted with the problem of water shortage.

Scenarios for the year 2050 show a slight change in spring precipitation and a considerable decrease in summer (up to 35%) and autumn (up to 15%) precipitation. In the worst case, mean precipitation (April to September) of less than 500 mm, critical soil water conditions lasting for weeks (results are related to the year 2050[6]) and an increase in summer drought have to be anticipated in the midlands.[9,10] The need for irrigation would increase at many locations, despite the earlier vegetation start (see section 2) mitigating the situation. The extent of local water shortage will probably depend not only on the water requirement of crops but also on local conditions[14] (see Water management chapter).

In extreme years, water scarcity could become a problem in fodder production as well, in spite of the fact that these areas are partly situated at higher elevations.

Uncertainties

It remains uncertain to what extent the development of irrigation plants to bridge dry periods makes sense, is feasible and possible in view of the availability of water in dry years. Avoiding risky locations and cultivating crops with lower water needs are to be preferred.

6. Pests and their relevance

Climate change enhances the emergence of weeds and favours insect pests, while the population of disease-causing fungi and bacteria are enhanced, inhibited or not affected, depending on the host plant.

Climate, weather and cultivation factors determine the type, extent and relevance of problems with weeds and pests. Climate change, in combination with increased goods and holiday traffic, has contributed to the spread of plant species that do not normally occur here (so-called "neophytes"). For example, *Ambrosia artemisiifolia* is currently being spread throughout Switzerland from Geneva and Ticino. Ambrosia is a weed that spreads quickly in fields and its pollen can cause allergies and asthma (see Health chapter).[15] With the increase in temperature, thermophilic species, such as weeds of subtropical origin with little nutrient content for animals, may spread as well. Woody plant species and root weeds like field thistle, sorrel and quitch may increasingly cause problems.[16]

Due to mild winters, autumn germinators, such as blackgrass and goosegrass, are being favoured. Weed pressure will probably increase as a result of the faster adaptability of the weed population and their greater competitive power compared to crops, as well as the reduced ground cover caused by heat waves and erosion.

As a consequence of climate change, additional problems are expected from insect pests.[17] Insect species like the European corn borer, the Western corn root worm, cereal leaf beetle, plant louse and potato beetle may develop more rapidly and spread farther than before. The prolonged warm period will enable pests that used to produce 1–2 generations per season, to produce 2–3 generations in the future (e.g., European corn borer). Pests that previously caused damage every three years (e.g., ladybird grubs), will appear at shorter and more irregular intervals. Due to warmer winters, the plant louse, which overwinters in the adult phase, will migrate from its winter locations to the crops at an earlier date.[18]

The occurrence of disease-causing fungi and bacteria is strongly dependent on climate and weather. Climate change will have a positive, negative or neutral effect depending on the host-pathogen system.[19] Mild winters and springs are favourable for brown and stripe rust, mildew and helminthosporium leaf spot diseases of cereals and corn. On the other hand, warm and rather dry summers will probably result in a decrease in moisture-loving diseases, such as glume blotch and fusarium head blight in wheat. Epidemics of late blight in potatoes would also be slowed, however, overall, due to an earlier start, probably not weakened. With corn, increasing feeding damage (European corn borer) and mechanical damage of the plants caused by the weather (hail, storms) will enhance toxin-generating fusarium fungi (see fig. 4). In addition, as a result of rising ozone concentrations, facultative parasites, which do not depend on their host to proliferate and are only found there occasionally, may increasingly cause damage to crops.[6]

Figure 4:
Infestation of a corn cob by toxic fusarium fungi. The occurrence of fusaria is caused through injury of the corn by insects, hail and growth cracks. It is enhanced by strongly changing climatic conditions.
(Source: H.R. Forrer, Agroscope ART Reckenholz-Tänikon)

Uncertainties

Due to the complex interactions between pests, beneficial organisms, host plants and cultivation methods, as well as the different effects of abiotic factors, such as heat, CO_2 and O_3, predictions regarding long-term trends are difficult. The only thing that is certain is that climate change will force us to face new problems at increasingly shorter intervals. Simplified crop rotation and focus on a small number of cultivated plant species also encourages problems with pests.

7. Food production from livestock

Fodder production productivity will increase as a result of climate change at locations with sufficient water supply, and as a result, livestock farming will profit from cheaper, increasingly domestically produced feed. The longer grazing period, as well as new, adapted fodder plant mixtures may increase the potential of animal production. However, negative effects are also to be expected: The increase in heat days will cause problems for livestock husbandry. Furthermore, feed quality may decline and yield security decrease due to more frequent extreme events.

Switzerland is a "fodder-production country": The prerequisites regarding precipitation volume and distribution are very favourable for fodder production (pasture). What's more, the topography of a large part of the area only allows for fodder production. The significance of hydroponic production is comparably small but increasing.

Traditionally, livestock husbandry was shaped by the effort to become more independent of climate variation (e.g., with climate control in barns, closed systems and conserved feed). In recent years, however, the use of grazing land has increased again. This is due to economic considerations (cost savings), and the effort to improve the well-being of the animals and to create more natural production. As a result, livestock husbandry has become more dependent on climate. However, strategies to deal with extreme climate situations are still only required in exceptional cases. Sporadically, conflicts may arise with particular housing systems, for instance with free-range systems during summer heat.

The expected future increase in the number of heat days will cause problems for animal husbandry: Water demand will increase and animals will increasingly need to be protected from high temperatures by adequate air conditioning in barns or by shading. In general, animal illnesses and parasites will probably not increase but shifts in the spectrum of pests cannot be ruled out. Already today, there are animal breeds that are better able to deal with these conditions, as well as with the previously mentioned changes. The breeding goals for breeds common in Switzerland need to be adapted.

In the future, due to climate change, fodder production productivity will tend to increase at higher elevations in locations where water supply is not a limiting factor. Animal production will profit from a better choice of cheaper domestic fodder. By breeding adapted fodder plant varieties (including new species) and developing suitable mixtures, this advantage can be enhanced. The lengthening of the grazing period (see section 2) results in additional grazing days and raises the production potential. In addition, the increase in suitable drying days could improve the quality of the conserved fodder. However, there are also negative effects to be expected: Due to the increase in weather extremes, the supply of fodder will become more irregular during the vegetation period and the dependency on fodder preserves will grow (see section 3). Fodder plants that are adapted to warmer growing conditions often have a lower fodder value. Furthermore, parasites (primarily fungal) develop more often in plants from temperate zones, affecting the fodder value and representing a risk to human and animal health. All these factors will have a varying impact depending on elevation and region. Production relocations are to be expected; alternatively the proportion of hydroponic or climate-indendent production could increase.

Uncertainties

It is unclear to what extent the decrease in the demand for fodder preserves as a result of the extended vegetation period and the increase in demand in order to bridge scarcity during growth periods will compensate each other. The area of conflict between controlled (intensive) and natural production will add another dimension. Although the number of potential grazing days will tend to increase, the number of optimal grazing days will probably decrease due to more days with high temperatures and drought. Regarding trampling damage in the case of overwet pastures, the situation is likely to improve.

8. Measures for crops, cultivation methods and farm management

Agriculture should be sufficiently adaptable to adjust to an average temperature increase of 2 to 3 °C by 2050, by taking suitable measures in the areas of species and variety selection, cultivation methods and farm management. However, the increase in weather variability and extreme events will be a challenge.

The current trend towards warmer and drier summers with more frequent extreme events requires an examination of the common crops, standard cultivation methods and the type of farm management.

Crops

The yield stability of many crops will probably decrease due to summer heat and drought. Therefore, the potential of existing and alternative crops needs to be evaluated. Today's varieties might possibly be replaced by more robust varieties or species that do not need to be newly bred but may already be available in corresponding climates. In the case of perennial, special crops (e.g., in fruit growing and viniculture), adaptation is less simple.

For the importation of new plant varieties, domestic competence in variety evaluation is important in order to achieve targeted selection (acquisition of know-how). Variety evaluation, with increased consideration of change in climate and pests, also serves to select competitive and broadly resistant varieties that are also distinguished by a greater weather, yield and quality tolerance.

In order to better distribute the risk of bad harvests, there should be a multifaceted mixture of crops without returning to small-scale cultivation (see Farm management section). At the farm level, in addition to fodder production, a higher yield stability can also be attained by combining varieties in the cultivation of cereals. Crops that cannot be adapted to the changing climate (e.g., oats) need to be replaced by new ones (e.g., soy, old rice). For special crops, a high added value may be achieved, for example, by cultivating more melons, grapes or citrus fruits.

Cultivation methods

Modern agricultural technology has already reduced the dependency of agriculture on the weather, leading to increased feed quality. In fodder production, cutting can be carried out at an earlier date (with smaller biomass or leaf area index), thereby attaining a higher quality. Further adaptation is possible in particular for intensive pasture management with maintenance measures, while this is less likely for extensive pasture management.[20] Crop losses in arable farming can also be reduced by adapting the sowing date to warmer temperatures. Thereby, new possibilities for the design of crop rotation arise.

The expected increase in summer drought will force farmers to economise water usage. Possible measures include early sowing, foliar fertilising in spring and preferably continuous soil cover consisting of living or dead plant material, as well as foregoing soil tillage operations in summer. At the same time, these measures impede soil erosion by heavy precipitation. The most consistent form of tillage to conserve soil texture is direct sowing (no-till). However, this requires accompanying measures against the spread of weeds, snails or fungi, particularly in wet weather, and in general against too strong competition from the soil-covering crops.

At locations with sufficient water supply for irrigation, the irrigation water needs to be used as effectively as possible. Measures include among others the consistent use of drip irrigation in row crops and the turning off of sprinkler systems during sunshine. In the end, plants should not be spoilt by irrigating too early or too often, so that they develop an efficient root system. The relevant know-how for Switzerland needs to be acquired and incorporated into training in the future.

Farm management

Global warming will extend the vegetation period and raise the number of available field workdays. These changes will affect farm management in the following ways:

Highly-mechanised cultivation methods with specific requirements for driving or cultivating soil become increasingly of interest. Expensive and efficient machines can better be used to capacity and – in the case of silage harvesting – be increasingly utilised with a time lag in mountainous areas (see fig. 5). Additionally, scheduling labour on short-notice becomes easier with more frequent fair weather periods. All in all, labour productivity will increase and production costs will drop. These advantages could, however, be nullified by more frequent storm damage or increasing insurance costs.

In mountainous areas, global warming will bring about a welcome shortening of the long winter feeding period. Thus, the demand for conserved fodder decreases, which not only makes the hay harvest easier but also reduces the building costs for fodder and fertiliser depots.

With decreasing summer precipitation, the risk of water logging and soil compaction will also decrease in mountainous areas. In particular, heavy soils are thereby less affected by soil compaction caused by heavy machines. The risk that soil water storage and holding capacity continue to decline and that susceptibility to erosion increases is also reduced.

Foresighted planning and risk assessment become more important. To reduce risk, prophylactic measures need to be taken, such as the inclusion of maps of natural hazards in the planning of land use, or the implementation of the natural hazards strategy of PLANAT.[21] A stronger diversification of farms should gain in importance again as a strategy to avoid risk. With arable crops as well as fodder production, the loss of one crop may be compensated for by another one. Due to job rationalisation, it makes sense to achieve a more multifaceted mix of crops within larger producer associations. Regarding foresighted planning, there is a great demand by practical agriculture for the improvement of the reliability of monthly and seasonal weather forecasts, as, for example, is currently being developed at MeteoSwiss.[22]

Uncertainties

It would be particularly useful in practice to have a seasonal forecast at hand for annual planning. This would support farm management, which will need to have a broader palette of measures available in the event that climate is more strongly influenced by extreme events.

Figure 5: In the harvesting of round bale silage, additional harvesting possibilities in early and late summer arise due to global warming. Expensive special machines may therefore be better used to capacity.
(Source: Agroscope ART Reckenholz-Tänikon)

9. National and global food supply

International agricultural markets play an important role in the estimation of the future national and global food supply. By 2050, the liberalisation of the markets and the adaptation of agricultural policy, in combination with the increasing demand of emerging nations on the world market will affect food supply more strongly than global climate change.

The effects of climate change on food supply in Switzerland have to be considered against the background of the foreseeable market liberalisation in agriculture in the coming decades. Due to the increasing interconnectedness of international agricultural markets, local markets will be less shaped by local conditions because the consequences are spread within a larger system. On the other hand, effects caused elsewhere will be felt at the local level. As a result of the complete opening of agricultural markets, production with comparative cost disadvantages will decline. Certain plant products may be more affected by this than livestock husbandry.[23]

On a global level, it can be assumed that agricultural production will be shifted to locations that become relatively more favourable from an agronomic perspective. For instance, Central and Northern Europe will be climatically more favourable locations, whereas semi-arid regions will be climatically disadvantaged. This may cause supply uncertainty at specific locations.

Global cereal production will generally decline and will move geographically. Due to the shift, and reinforced by trade liberalisation, agricultural markets and the international trade will become more important. Due to expected shortages, world market prices will rise. However, the effects on agricultural markets will largely depend on the general economic and global political situation, and will vary spatially. The global distribution problems will intensify. In addition, larger price fluctuations are to be anticipated due to the expected increasing intensity of meteorological extreme events. In particular, African countries will suffer from the consequences of climate change. The solidarity of northern countries with those in the south in terms of food supply will become more important.

In Switzerland, the contribution of agriculture to the GDP is marginal. The consequences – both positive and negative – of climate change on agriculture are therefore macroeconomically insignificant. Food demand in Switzerland can be covered by imports and supply problems are not expected.

As Switzerland is located in a climate zone that tends to be favourable, the comparative advantages of the location will increase. Generally, an increased risk is anticipated, which will be amplified by the structural changes that result in larger, more capital intensive farms with a higher degree of specialisation. However, structural change will also result in improved agility, professionalism and adaptability of the farms.

Uncertainties

The significance of the direct effects of climate change on domestic agriculture by 2050 remains uncertain in the context of other changes, mainly caused by alterations in international trade.

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Water management

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1. Introduction

Background

Water management includes all human activities related to water use, water protection and protection against water risks. Climate change affects these aspects of water management through changes in the water cycle (see Background chapter).

In the following chapter, the effects of climate change on the water cycle are discussed in detail for the following areas:

- Changes in natural waterbodies (lakes, biodiversity, fish)
- Water-related natural hazards (floods, drought)
- Water resources and water demand (groundwater recharge, demand for drinking and industrial water)
- Water utilisation (energy, Rhine shipping)
- Management of water resources

Climate change also influences other aspects of water management, such as inland shipping, the recreational value of water and water use in the production of goods. Although these and other topics are also important, they will not be covered here.

Water management is not only affected by climate change but in particular by human activities. In the past, population pressure, changes in land use, water use and water pollution were the relevant factors that led to continuously changing water management. As a result of climate change, not only the changes in water management need to be considered but now also changes in water resources. It is not clear whether changes in water resources or use will be more important in the future. In the worst case, the developments will go in opposite directions (decrease in supply and increase in demand).

Overview

Low water levels

In comparison to other regions of the world, Switzerland is in a favourable situation today, with about 5560 m^3 water available per year and per inhabitant (Israel 115, the Netherlands 690, Germany 1305, Spain 2785 m^3 a^{-1} E^{-1}). Abundant precipitation, as well as the balancing effect of snow cover and – to a decreasing degree – glacier melt, will also ensure a comparably rich water supply in the future.

As a result of climate change, the water supply in summer and autumn will decrease (see Background chapter). In particular, during the more frequent heat-wave summers even medium and larger midland rivers may have water levels as low as in winter. Accordingly, groundwater levels in valley gravels will decline more strongly in late summer and autumn.

At the same time, the agricultural demand for irrigation water will increase. As a result, competition will rise between the water demand of river ecosystems and different users and regions, in particular in the use of groundwater, and small and medium rivers. This competitive situation has different results:

- In agriculture, there may be production losses due to water shortage.
- Electricity production will be affected by reduced water supply and increased water temperatures (hydropower, withdrawal of cooling water).
- In Rhine shipping, limitations are expected in summer and autumn.

Floods

The damage potential of floods has increased considerably within the last 50 years. The reason for this is population and economic growth; valuable infrastructure is increasingly in exposed positions. This development will continue in the future.

Today's climate scenarios show an increase in mean precipitation, and in the frequency and intensity of intense precipitation in the winter half of the year. In addition, precipitation will fall more frequently as rain instead of snow. Due to these changes, an increase in flood frequency, particularly in winter, can be expected and may lead to higher flood water levels, primarily in the midlands and the Jura, as well as in the foothills of the Alps below about 1500 m a.s.l. For summer, no clear statements are possible so far.

The expected increase in damage potential, as well as the possibility of more frequent floods, requires greater protection against floods. A possible answer to these uncertainties are so-called "no-regret" measures, such as, for instance, sustainable flood protection: In the case of unchanged flood intensity, renatured and broadened rivers are a plus for river ecosystems; in the case of an increase in flood intensity as a result of climate change, the higher risk will be at least partly compensated for and minimised through the allowance for overload.

Ecology

The increase in water temperatures will also have unexpected effects on aquatic ecosystems, which, however, cannot yet be assessed.
In lakes, the warming will lead to a more stable concentration stratification and to a decrease in oxygen content in the deep water. This will increase the risk of oxygen deficiency in mesotrophic and maybe also in oligotrophic lakes.

Measures

Regional/superregional management of resources lends itself as a measure against water shortage. This requires a change in thinking in the direction of integrated water management of entire river catchments.
Lake management results in a reduction of and a shift in fluctuations. In the future, existing regulating schemata will need to be adapted to changed conditions (new target functions and optimisation). In the future, pressure will increase to manage lakes that are not regulated today. It is unclear what ecologic problems this entails. Effects on riverine vegetation are to be expected, for instance, on reed population and other vegetation communities that depend on the natural fluctuations of the water line.
The flexible floods strategy in Switzerland comprises measures in city and regional planning to limit the damage potential, property protection to reduce vulnerability, constructional protection measures and emergency measures in case of overload. The strategy proved its value during the flood of August 2005. Wherever the strategy had already been implemented, the damages were significantly reduced in comparison to similar floods. Regular examination of the risk situation is a prerequisite to implementing the strategy effectively in the long term, since both damage and danger potential change continuously.
In the future, alpine storage lakes could increasingly serve to retain flood peaks. The use of multipurpose facilities will gain in importance.

Links to other topics

Agriculture

Agricultural demand for irrigation water, production losses due to shortage in irrigation water

Tourism

Effects of water-related natural hazards on tourism, effects of the changed water resources on tourism (lower water levels in lakes and streams in summer: bathing / passenger boating), water supply for snow-making machines

Energy

Production of hydroelectric power with reduced supply in summer/autumn, impact of extreme events on hydropower, impact of temperature increase on the use of cooling water by thermal and nuclear power plants with once-through cooling (Betznau and Mühleberg), changes in energy demand in summer and winter

Financial management

Investment needs, damage insurance

Infrastructure

Flood protection, irrigation plants, canalisation, linking-up of different systems in terms of integrated water management

2. Changes in natural waterbodies

Water temperature

Climate change directly affects water temperatures. In Switzerland, water temperatures in rivers and in the surface layer of midland lakes will have increased by about 2 °C by 2050 compared to 1990.[1] In midland lakes, the risk of oxygen deficiency in the deep water will increase.[2]

In the last decades, water temperatures in rivers have risen in parallel to air temperatures (fig. 1).[3] In lakes, the warming was stronger in the well-mixed surface layer than in the deep water. As a result, the stability of density layering has increased and the period of stable layering in summer lasts longer. In the lake of Zurich,[4] a mean warming of 0.24 °C per decade in the surface layer and 0.13 °C per decade in the deep water has been observed. Stable layering lasts about 2 to 3 weeks longer.

In the midland lakes with no regular ice cover, the frequency of mixing events in winter has tended to decrease. As a result of this, less oxygen reaches the deep water. This is not true of lakes at higher elevations that are regularly covered with ice; there instead, the mixing takes place earlier in spring and later in autumn.

According to the scenario, rivers will warm by about another 2 °C by 2050 compared to 1990. In the midland lakes, the surface layer will continue to warm more strongly than the deep water, and the stability and the duration of density layering will continue to increase. The length of the period during which complete mixing is possible will be further shortened, the frequency of complete mixing events will continue to decrease and oxygen input into the deep water will be reduced. In lakes where the oxygen content is sufficient today, the risk of oxygen deficiency in the deep water increases.

With climate change, the midland lakes at lower elevations are expected to freeze more rarely, and at higher elevations, the ice cover will last for a shorter period of time. In mountain lakes, the decrease in the annual ice cover will lead to an increase in biological production and an increased oxygen demand.

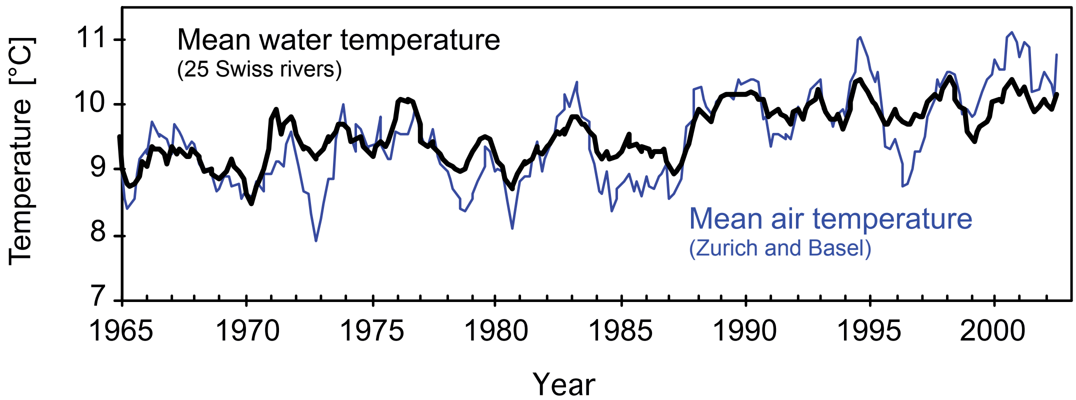

Figure 1: Since 1965, the increase in mean water temperature in Swiss rivers (black curve) has run in parallel to the increase in mean air temperature (blue curve).[3]

Micro- and small organisms

Water temperatures in the surface layer of lakes have increased in winter in the past decades, which has resulted in an increase in the thermal stability and a change in circulation conditions. This has resulted in temporal shifts in the food chain and, in lakes with sufficient oxygen content, in a decrease in phytoplankton diversity. As a consequence of future warming, living conditions in lakes with currently sufficient oxygen content may deteriorate.[2]

Today's state of knowledge does not allow comprehensive predictions to be made about the changes in aquatic biodiversity by 2050. Adaptability and adaptation speed are species-specific and cannot be predicted. However, single changes can be qualitatively foreseen.

In lakes, the food chain will undergo a temporal shift due to the warming. In spring, the feeding pressure of zooplankton ends algal bloom. What follows is the so-called "clear-water" phase. Since the growth and feeding rates of zooplankton are higher with warmer than with cooler water temperatures, the clear-water phase occurs earlier after warm than cold winters. In the past 20 years, the clear-water phase has been observed to occur about two weeks earlier. According to the climate scenario, the clear-water phase will continue to occur earlier in the future, although, this is not possible indefinitely.

Since the seventies, winter phosphate concentrations have decreased due to cost-intensive measures (wastewater treatment, closed circular pipeline). At the same time, an increase in phytoplankton diversity has been observed. In the past decades, warm winter temperatures have had a negative effect on phytoplankton diversity in lakes with sufficient oxygen content. This development will probably continue with future warming. In lakes without sufficient oxygen content, the influence is not clear.

Fish

The warming of waterbodies affects cold water fish; their suitable habitats are reduced and species composition changes. Cold and warm water fish will profit from the warmer winters.

For fish, human interference in the hydrology and morphology of waterbodies were important influencing factors in the past. This will also be the case in the future.

As a result of the warming in Swiss streams by 0.4–1.6 °C in the past 25 years (fig. 1), trout habitat has shifted upwards by 100–200 m.[3] A similar development was observed in North America: In the Rocky Mountains, the habitat suitability for trout decreased by 17% with a warming of the water by 1 °C in July.[5]

Estimates have shown that with a warming of 2 °C by 2050, the habitats of salmon in Switzerland will shrink by $^{1}/_{5}$ to $^{1}/_{4}$ compared to today. Cold water as well as warm water fish will profit from warmer winter temperatures; growth phases last longer and the fish grow more quickly. As a result, waterbodies will become more suitable for carp (Cyprinidae) and exotic fish species.

Illnesses like the parasite infection PKD (Proliferative Kidney Disease) will spread with warmer water temperatures.[6]

3. Water-related natural hazards

At elevations below about 1500 m a.s.l., more frequent and in part larger floods are expected in winter and spring as a result of climate change. In summer, drought periods will increase significantly.

Floods

The formation of floods is largely determined by the precipitation regime. In the past, there were periods with many floods as well as periods with few floods. In the past approx. 20 years, large floods seem to have occurred more frequently (summer 1987, September 1993, May 1999, October 2000, August 2005) in comparison to earlier decades in the 20th century.

An analysis of trends in measured runoff[7] of small and medium catchment areas in Switzerland (period 1930–2000) showed an increase in the annual discharge in many of the rivers studied. The increase was primarily caused by the increase in discharge in winter and spring. The observed increase in intense winter precipitation[8] can explain at least a part of the observed discharge trends.

According to today's knowledge, different changes in the precipitation regime that could affect flood frequency are possible in the future (see Background chapter). In winter, an increase in mean precipitation is expected. Precipitation will become more frequent and fall more often as rain instead of snow up into higher elevations. Both factors could bring about an increase in mean runoff in winter and into spring.[9,10] In addition, many analyses of global and regional climate models show that the mean precipitation intensity in winter and the frequency of heavy and extreme precipitation events could increase in Central and Northern Europe.[11,12,13,14] The analysis of recent model results also shows an increase in heavy precipitation in Central Europe for spring and autumn. Model results for summer display large variability. At present, qualitative statements for this season are almost impossible but in many models, the decrease in mean precipitation is accompanied by an increased precipitation intensity.[11,15]

In addition to the intensity and duration of precipitation events, the condition of the catchment area plays an important role in the formation of floods. Runoff ability will tend to deteriorate due to the increase in mean temperature and the decrease in precipitation in summer.

As a result of the expected changes in the precipitation regime, more frequent and in part larger floods are expected than under current climate conditions, in particular in winter and the transitional seasons, and mainly for medium and large catchment areas of the Jura, the midlands,

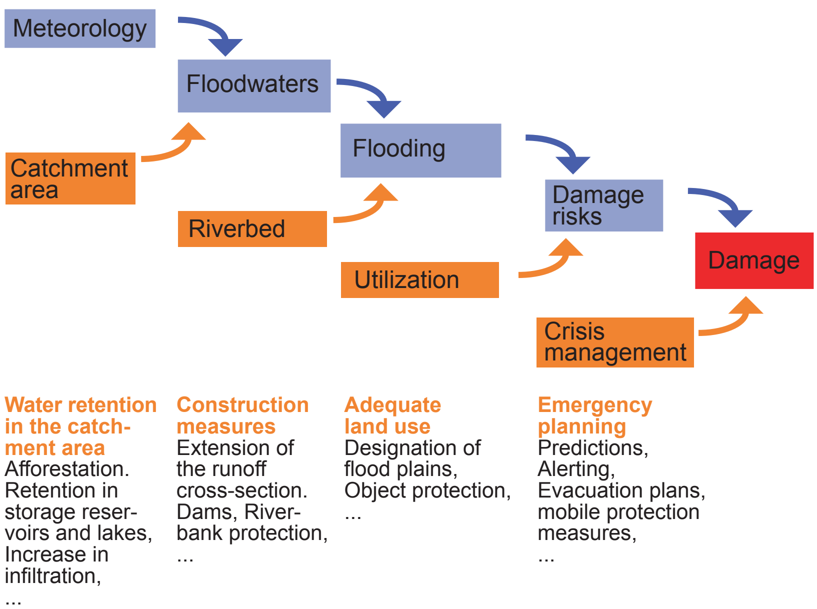

Figure 2:
Flood damage only occurs when a number of preconditions are fulfilled. The possibilities for intervention are accordingly numerous.

Redirection under overload conditions

In order to limit damage to a tolerable level in the case of an extremely large flood, the floodwaters are redirected to less vulnerable areas. In the flood of August 2005, this emergency measure was implemented. 25 to 50% of the flood discharge was directed onto sports fields, agricultural areas, car parks and other areas around the settlement area that were less sensitive to damage. Such measures must be prepared for with construction and spatial planning.

Figure 3: In August 2005, the flood of the Engelberger Aa was redirected around the vulnerable settlement area. (Source: Swiss Air Force 2005)

the foothills of the Alps and Ticino. In addition, the temperature increase will cause more frequent changes between snowfall and snowmelt, so that more often on the alpine border several days' accumulated precipitation results in runoff. Since evaporation is low in winter, no notable compensation effects are to be expected.

In small catchment areas of the midlands and in the Alps, the biggest floods usually occur in summer after short but heavy thunderstorms. It is very uncertain whether and in what direction a change in frequency will occur.

In the high mountains, floods are not expected to be affected significantly, since winter precipitation, even if it increases, does not generate floods due to the portion of snow. In spring, an intensification of snowmelt is expected. This could lead to an increase in flood risk when snowmelt and precipitation events overlap. Less meltwater and drier soils are generally expected in summer.

Flood damage results from the conflict between the natural extension of floods and human use of the catchment area (fig. 2). In the past 50 years, damage potential due to floods has markedly increased in the course of economic development. Infrastructure is increasingly located at exposed locations. The higher damage potential requires increased protection against floods irrespective of climate change.

Switzerland pursues a flexible strategy in flood protection, which, in the first instance, aims at avoiding damage rather than at preventing floods at all costs. It comprises a set of measures that given the uncertainties must be applied in combination. The following principles are thereby important:

- A further increase in damage potential is to be prevented by spatial planning measures; the construction of new buildings in areas at risk is to be avoided.

- For existing buildings and buildings in lower-risk areas, the damage potential is to be reduced by the appropriate property protection. In so doing, a further increase in the damage potential and the requirement for protective structures at watercourses can be reduced.

- Protective structure measures are taken if spatial planning and property protection do not suffice. Their design should be in accordance with economic principles, which implies a differentiation between protection goals, that is, higher values are to be better protected. Designs for existing settlements are usually based on floods occurring every 100 to 300 years.

- Independent of the validity of the calculated probability for design floods, an even larger flood can occur. Emergency planning must be arranged for such an overload case. This aims at limiting damage to a tolerable level in the event that the design flood is clearly exceeded. The concepts may include evacuations, mobile barriers or emergency discharge (see box).

The fundamental advantage of this strategy is the dimensioning of protective structures based on known probabilities. Their cost-effectiveness is therefore assured for today's conditions and even more so in a future climate with an increased risk of flood. The inclusion of a considerably larger flood in planning ensures damage limitation up to a certain degree, even in the case of an increase in flood risk. It saves time until a more reliable basis for the development of the risk situation is available. Continuous monitoring of the risk situation is a pre-condition for long-lasting effectiveness, since both damage potential and the danger conditions change continuously.

Drought

Switzerland experienced the last summer droughts in 1947 and 2003. For agriculture, the heat-wave summer of 2003 caused damage amounting to about 500 million Swiss Francs. However, there was not a life-threatening water shortage. In the course of the 20th century, no systematic trends in the frequency of rainless periods were detected.[8]

According to the scenario, precipitation will decrease in summer and the probability of drought periods will increase. Extreme drought periods will also become more frequent according to model calculations.

Today, Switzerland is in a favourable situation in comparison to other regions of the world. Plentiful precipitation as well as the balancing effect of snowmelt and – of decreasing relevance – glacier melt will provide comparably substantial water resources also in the future. In order to avoid shortages in water supply, the corresponding infrastructure needs to be appropriately upgraded in time. Requirement forecasts and construction periods need to be considered in the planning.

In discharge regimes in the high mountains, which are shaped by the winter snow cover and snowmelt, higher water levels might be reached during low water in winter, due to higher temperatures and increasing winter precipitation.

4. Water supply and demand

Groundwater recharge

Groundwater recharge will tend to increase in winter and decrease in summer and autumn as a result of climate change. Overall, groundwater levels will decrease slightly.

In Switzerland, 83% of the drinking and industrial water demand is covered by groundwater; 44% of which come from springs in karst and fissure aquifers and 39% from filter wells in unconsolidated rock (see fig. 4). Unconsolidated rock aquifers have a slow groundwater flow and are generally plentiful. In karst areas, the groundwater drains off quickly, which is why springs there show a large discharge after rain. Springs in fissured rock areas show a steadier discharge but are generally less plentiful. The different aquifer types therefore react to climate change to a different extent and with a different delay.

As a result of the predicted climate change, groundwater recharge will tend to increase in winter as a result of increased precipitation in the form of rain. In summer and autumn, groundwater recharge will decrease in the midlands and in the foothills of the Alps due to higher temperatures, more frequent drought periods and the concentration of intense precipitation. Infiltration from alpine surface waters will decrease slightly.

As a result of these changes in groundwater recharge, spring deliveries in near-surface wells with small catchment areas and in karst aquifers will fluctuate more strongly from season to season, and may partly run dry in summer and autumn. In groundwater reservoirs in valley gravels with a midland flow regime, groundwater levels are expected to fall in summer and autumn. Groundwater reservoirs in valley gravels with an alpine flow regime, which exhibit their seasonal peak in summer, will experience only slightly falling water levels. However, even here lower groundwater levels must be expected during the more frequently occurring heat wave summers and absence of glacier melt in late summer and autumn. In aquifers at lower elevations, a slight decrease in groundwater levels is also expected.

Figure 4: Distribution of the different aquifers in Switzerland.[16]

Demand for drinking and industrial water

As a result of climate change, competition between different water uses and users will become more frequent. The requirements for drinking water supply will be affected regionally and temporally. In agriculture, the demand for irrigation water will increase.

Climate change will affect the requirements for drinking water supply. The effects are regionally and temporally very different. Measures against drinking water shortages and to increase supply security include the use of surface water (lakes), the expansion of the integrated networks of the drinking water supply and the development of new groundwater resources.

Water resources will decrease in the soil due to decreasing precipitation in summer. Higher temperatures lead to an increase in evaporation and in the demand of plants for water (transpiration). As a result, longer-lasting and more frequent drought periods will lead to soil dehydration. Consequently, the water absorption capacity of the soil declines due to crustification and water retention capacity declines due to desiccation cracks; the ability to produce humus decreases.

Reduced water supply and increased agricultural demand for irrigation water will lead to a competitive situation between different uses und users, such as with downstream users. In summer, water – limited temporally and spatially – will increasingly become a scarce commodity. Thus, the necessity of suitable management will increase, which will affect the priorities, rights and prices for use. Compensation and irrigation measures will require rules as well as new infrastructure.

5. Water use

In Switzerland, water is extensively used for energy production. As a result of climate change, electricity production by storage and run-of-river power stations will decrease. In the future, Rhine shipping will increasingly be affected by extended periods with unusually low water levels.

Energy

In Switzerland, water power covers about 60% of the demand for electricity or $^1/_8$ of the entire energy demand.

Climate change will lead to a seasonal balancing of discharge regimes, particularly in the Alpine region. Water flow will increase in winter and spring, and decrease in summer and autumn. As a result, power plant operators gain more flexibility. In the future, the use of water-storage space will be adjusted not only to the balancing of seasonal fluctuations but also to the fluctuations of the electricity market. Overall, a loss in hydroelectric energy production by storage power stations must be anticipated, since less water will be available; annual rainfall will decrease and evaporation increase.

Low water levels in late summer and autumn will limit the electricity production of run-of-river power stations in the midlands. On the other hand, these power stations can profit from the increasing discharge in winter and spring, since the capacity of turbines at that time of year are hardly working to full capacity today.[17] Altogether, a minor decrease in electricity production by run-of-river power stations is to be expected.[18]

Floods and slope instabilities will increase with climate change, and in particular large mass movements can endanger auxiliary facilities of power plants, such as water catchments on steep slopes. Sediment, bed load and debris flow transport could increase, intensifying and accelerating the silting up of storage lakes.[19,20]

The production in nuclear and other thermal power plants will also be affected by climate change. Due to increasing water temperatures and decreasing discharge, they will not be able to obtain as much cooling capacity from the water as today, in particular during heat waves like in the summer of 2003.

Due to climate policy, water power as a renewable CO_2-free energy will gain economic advantages.

Rhine shipping

15% of the amount of foreign trade is transacted using Rhine ports; for mineral oil products this is as high as 35%. 9 million tons of goods are transported into Switzerland on the Rhine each year.

During low and high water, Rhine shipping may be restricted. In 2003, transported tonnage and transport performance showed a decrease of 5.8 and 9.9%, respectively. This decrease was primarily due to the low water levels in the second half of the year. Due to the low water, the ships were not able to carry as much compared to normal water levels. In the case of high water, Rhine shipping is suspended when a water level of more than 4.30 m at Rheinfelden is reached. In May 1994, the stretch between Basel and Rheinfelden was closed for 13 days. In February 1999, shipping was interrupted for five days and from 12 May until 16 June for another 38 days.

Climate change will have an impact on discharge. Today, the Rhine has a stabile discharge thanks to meltwater supply and precipitation in the Alps in spring/summer, and precipitation in lower lying areas in autumn/winter. The meltwater of the winter snow cover and of glaciers is currently an important source for regular discharge at times of low precipitation. This balancing effect will continually decline with the melting of glaciers. The probability of extended periods with unusually low water levels will increase by 2050. Although this will not affect the survival of Rhine shipping, it will probably affect the temporal reliability. Progress in the seasonal forecasting of weather dynamics and therefore of water levels will simplify logistic planning and enhance planning reliability.

6. Intensified management of water resources

Today, Switzerland has a spatially and temporally relatively stable water supply. Due to climate change, the natural water supply will not be able to cover the future demand everywhere all of the time.

As a result of climate change, alpine discharge regimes will become more stabile and the midland regimes will experience increasingly low water and dry periods. According to the climate scenario, heat waves and dry spells will become more frequent. This means that water – restricted temporally and spatially – will increasingly become a scarce resource in summer. The requirements for water utilisation will also change with climate change. In the case of low water levels, lake users and downstream neighbours will increasingly request an increase in discharge for shipping, water protection requirements, drinking and irrigation water extraction, and for recreation. The seasonally and regionally reduced water supply, and the change to the claims on water use make it necessary to manage water on a quantitative basis. Without water quantity management, it will not be possible to meet all demands to the same degree.

For regulated lakes, the existing regulating schemes need to be adapted to future requirements. For lakes that are not yet regulated (e.g. Lake Constance), the call for regulation will increase.

Intra-regional management means that water management facilities (integrated networks, as well as storage and lake management) would need to be accelerated in order to ensure the required balance between (natural) supply and demand.

Integrated management at the level of catchment areas requires administrative-institutional adaptations (revision of responsibilities, coordination) on the organisational level, as well as legal adjustments, since the small-scale responsibilities that have existed up until now do not provide an efficient structure.

Along with management approaches, measures are also required on the demand side, in particular for agriculture (from more efficient use of irrigation techniques to the choice of planted crops), and for industrial and drinking water.

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Health

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1. Introduction

Background

Climate change does not affect human health in an isolated way but in combination with other socio-economic and ecological changes.

A change in climatic conditions affects human health in a variety of ways. An increase in the frequency of extreme events, such as heat waves, storms and flood, may have fatal consequences, the distribution of disease, e.g. tick-borne meningitis or salmonella poisoning, may change, for instance of tick-borne meningitis or salmonella poisoning, and the danger of food poisoning increases with rising temperatures.

However, most of these trends are not solely affected by climate change but by other factors as well. Thus, for the spread of malaria in Switzerland, the natural surroundings (e.g. bogs) and hygienic conditions are of major importance, whereas the climate is of minor importance.

The following chapter discusses possible climatically caused changes that will affect health in the coming 50 years, and that may be of relevance for social and health care policy. The following topics are covered in detail: heat waves, extreme events, food poisoning, respiratory diseases, vector-borne diseases and water pollution due to floods.

Areas where experts consider the impact of climate change to be minor have not been taken into account. This mainly relates to the problem of introducing illnesses by migration. Migration increases the danger of spreading infectious diseases and of introducing germs unknown to the local population. Furthermore, illnesses that have already been eradicated, such as polio and tuberculosis, can be reintroduced. Here, climate is only a minor factor, with such migration mainly occurring for other reasons. Environmental refugees mostly move to neighbouring countries rather than to far off industrial countries.

Apart from the mentioned areas with negative effects, there are also some positive developments to be expected, in particular regarding cold and frost periods. With increasing warming, their frequency and the associated mortality decrease. Cold periods with a significantly increased mortality are already very rare and big changes are therefore not to be expected. However, the fact that society will be ill-prepared for severe cold spells because they occur more rarely could have negative consequences and result in more serious health effects.

Secondary benefits to the health sector

Measures to reduce greenhouse gas emissions also result in a reduction of air pollutants and thereby lead to a decrease in the frequency of respiratory and cardiovascular diseases (secondary benefits).

The effects of climate protection measures are not discussed in this chapter. Emission reduction measures will have hardly any effect on the expected temperature increase before 2050; they will have a significant effect only in the second half of this century. However, the reduction in harmful air pollutants will be immediately noticeable in the health sector. It will, for instance, cause a decrease in respiratory diseases.

Overview

In Switzerland, the question of the relationship between climate change and health has become the centre of attention as a result of extreme events, such as the heat-wave summer of 2003, or the observed slow increase in tick-borne diseases.

Heat waves

In Switzerland, the likely increase in heat waves represents the most important climate-induced change in the health sector. The heat-wave summer of 2003, which resulted in 1000 additional deaths, demonstrated the susceptibility of the population. Similar conditions are to be expected every few years from 2050 onwards.

Humans can adapt to higher mean temperatures to a limited extent, as experiences from southern countries have shown. However, adapting to the occurrence of heat waves at short notice is more difficult. In spite of this, the increase in mortality caused by heat waves can be mitigated by adequate measures. The question of how quickly the human organism is able to adapt to new and warmer conditions remains open.

Heat waves also affect job performance and therefore have economic consequences. For temperatures above 30 °C, a reduction in the mental and physical job performance is detectable.

Other extreme events

The likely increase in extreme events, such as floods, mudslides and probably more severe storms, also has a direct impact on health. Such events cause deaths and injuries, as well as severe psychological effects. These effects can only partially be mitigated by preventive measures (protective structures, zones with building bans, flood plains, etc.).

Food- and water-borne diseases

With rising temperatures, in particular heat waves, the danger of food poisoning due to spoiled food and the risk of food-borne diseases (e.g. salmonella) increases. This mostly affects private consumption, where in the course of societal changes the knowledge about how to deal safely with food is declining.

The risk of water-borne diseases is unlikely to increase. Even though floods can result in sewage and toxic substances entering open bodies of water, the danger of drinking water contamination and the transmission of diseases is relatively small in Switzerland thanks to the wide separation of drinking water and sewage systems and the well-controlled drinking water supply.

Harmful substances

Warming may increase the frequency of respiratory diseases due to a higher concentration of ozone and possibly as a result of higher concentrations of biogenous airborne particles, such as pollen or fungal spores.

Vector-borne diseases

For various diseases caused by so-called "vectors" (carriers of infectious diseases) considerable changes may occur. The estimation of these changes, however, is still rather uncertain. In Switzerland, the spread of exotic diseases that only affect humans, like malaria or dengue fever, is rather unlikely. On the other hand, diseases that can be transmitted from animals to humans, e.g. West Nile fever, are on the rise. Higher temperatures could also produce new vectors or result in a host change, including the possibility of humans becoming a host.

It is also not clear how the frequency of tick-borne diseases will change. Ticks require a specific temperature as well as a specific humidity in order to spread. Due to these two factors, their distribution in Europe has northern and southern boundaries, currently in Northern Sweden and Italy, respectively. A temperature rise influences the activity period of ticks, as well as possibly their infection rate and the leisure time activities of people. At present, there is an observed increase in the number of reported tick-borne encephalitis cases in Switzerland.

Links to other topics

Agriculture

Pollen concentrations are related to changes in agriculture. Thus, the cultivation of other agricultural crops or a shift in the cultivated quantity changes the associated pollen concentrations.

Infrastructure

The impairment of job performance due to heat is closely related to changes in infrastructure. The consideration of future temperature conditions in architecture and in the planning of industrial and office buildings, is not only important with regard to work conditions but also in terms of other structural engineering issues.

Water management

The frequency of floods will be influenced by flood control measures. Floods and drinking water supply also have an important impact on water management.

Following is a presentation of the different areas in which effects of climate change are expected. The order reflects the decreasing relevance of the expected changes to health.

2. Heat waves

In Switzerland, the likely increase in heat waves by 2050 will be the most important climatically induced change with regard to health. The 1000 additional deaths caused by the heat-wave summer of 2003 demonstrated the sensitivity of the population. From 2050 onwards, similar conditions may occur every few years. Short-term measures include informing the population and introducing early warning systems. In the long term, adapted construction methods and city planning may enhance well-being. It is unclear how quickly the population is able to adapt to new climatic conditions.

Heat and mortality

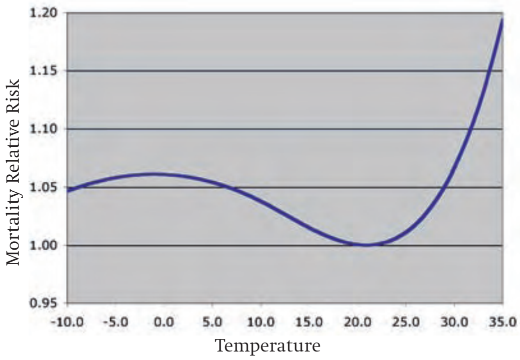
An increase in heat waves is an undisputed result of the increase in mean temperature. When the mean temperature rises, the probability of events that are rare today rises as well. It is not yet clear whether the distribution of the temperatures merely shifts in parallel to the mean temperatures, or whether the variance of single years also increases, as some studies suggest.[1,2]

Mortality shows a clear dependency on temperature. Mortality rises considerably when the temperature threshold of a specific region is exceeded. Fig. 1 illustrates the relationship between mortality and wind-chill factor on the northern and southern side of the Alps within the period 1990–2003. The regional difference is clearly evident: The “optimum” temperature with the lowest mortality rate is about 3.5 °C higher on the southern side than on the northern side of the Alps. That means that people adapt to generally higher ambient air temperatures physically as well as by attitude changes and technical measures. In order to consider the effects of climate change, the question therefore arises how quickly adaptation takes place. Based on the experiences of 2003, changes in behaviour could already be observed in 2005 (sunscreen, cooling, etc.).

The heat-wave summer of 2003 clearly showed that severe heat waves can cause considerable health problems and additional deaths. Direct consequences are, for instance, heat-related cardiovascular problems, heat stroke, dehydration (drying-up of the body) and hyperthermia (overheating). Elderly people and those in care are most often affected.

In 2003, heat waves resulted in a significant increase in the mortality rate in the affected regions in Central Europe (France, Southern Germany, Switzerland, Northern Italy and Spain)[3], in particular in cases where information and care of risk groups was absent. Europe-wide, the number of additional deaths was estimated at ca. 35,000.

In the summer of 2003, mean temperatures were about 4 to 5.5 °C above the long-term average. This lies approximately within the upper threshold of the expected temperature increase by 2050. In this case, assuming that the vari-



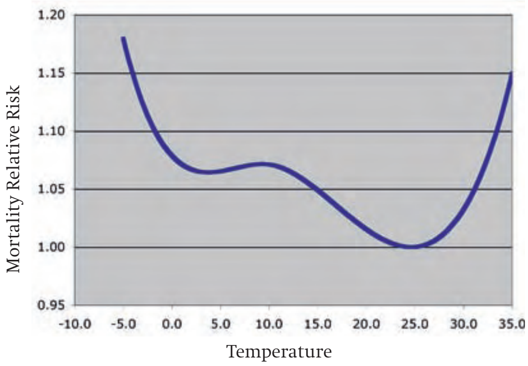


Fig. 1: Relationship between mortality and temperature on the northern (left) and southern side (right) of the Alps within the period 1990–2003. The temperature range with the lowest mortality lies at ca. 21 °C on the northern side of the Alps, about 3.5 °C lower than on the southern side, with ca. 24.5 °C. (Data source: L. Grize, ISPM Basel)

ability of annual summer temperatures does not change, the conditions in 2003 would therefore already correspond to the average in 2050. Even for the medium scenario with an average temperature increase of about 2.5 °C, the 2003 values would occur every few years.

The summer 2003 heat waves caused about 1000 additional deaths in Switzerland, of which about one third is attributable to the elevated ozone concentrations. It is probable, that a portion of the heat-related deaths included people who were in a critical state of health and who would have died soon even without the heat. The greatly increased mortality rate can, however, not solely be explained by these cases, as no compensatory decrease could be observed in the following months.

Heat and work

Humans need to keep their core body temperature constant. It is raised by physical labour, and with it the tolerance for heat declines. Heat waves can affect job performance. In medium latitudes (Central Europe, US, Australia), a decline in mental and physical job performance is detectable at temperatures above 30 °C.[4,5] High humidity in combination with heat further impairs job performance.

People are able to adapt to a slow increase in the mean temperature. A comparison with southern countries shows that labour and efficiency are indeed possible at higher temperatures. Thus, the future increase in mean temperature will have little effect on job performance. In contrast, rapid adaptation to heat waves is difficult. Therefore, the expected increase in heat waves may negatively affect job performance if adequate adaptations or measures are missing.

Repeatedly in the past, the working environment changed rapidly and strongly due to innovations. Thus, 40 years ago, the spread of computers and internet was not foreseeable. In parallel to this development, the majority of jobs in Switzerland in recent decades have switched from physical outdoor activities to sedentary work in offices and indoors. The future relevance of climate to the working environment in comparison to other changes is therefore hard to estimate.

Measures and uncertainties

The effects of heat waves can be mitigated by various measures, such as early warning systems, organising the care of high-risk groups and informing the population. The first measures were taken in Switzerland after the heat wave summer of 2003. The Federal Office of Public Health made information and fact sheets available[6], and MeteoSwiss (Federal Office of Meteorology and Climatology) set up a heat-wave early warning system.

The widespread use of air conditioning is considered problematic from the perspectives of energy use and climate policy, since energy use increases and – depending on the source of energy – greenhouse gas emissions rise (see Energy chapter). Well-being can be increased through improved and adapted construction methods, such as better insulation and smaller windows in buildings, or ventilation shafts and green belts in cities. In this regard, city planning is particularly challenged because health problems due to heat predominantly occur in cities. Not to be forgotten is the danger that protection against the cold is neglected because cold spells are getting rarer. Extreme cold spells may therefore have more serious health effects.

During hot periods, the work situation can be improved by adapting working hours or by introducing longer breaks (siestas). In the case of extreme heat, health risks may be mitigated by extra days off.

The most important open question concerns the time it will take individuals and the entire population to adapt to the new conditions. A comparison of the relationship between temperature and mortality for the years 1960–1975 with current numbers could provide an indication of the adaptability of the population over a few decades. It is also not clear to what extent the weather conditions of the previous winter influence the health effects of a heat wave in the following summer.

3. Other extreme events: floods, landslides, storms

The risk due to natural hazards also grows with the increase in extreme events. Floods, mudslides and stronger storms result in death and injuries, and also have severe psychological effects. These effects can only partially be countered by preventive measures (protective structures, etc.).

The frequency and intensity of extreme events will change as a result of climate change[7] (see also Extreme events section in Background chapter). Floods and debris flows will probably increase due to more frequent heavy precipitation (see fig. 2). Rockfalls will probably increase as well. Based on current understanding, the higher energy content of the atmosphere will not affect the frequency of storms but rather their strength.

Extreme events sometimes have disastrous effects. They cause death and result in damage to property. The latter may seriously impact health if the properties affected are important for supply and health care (hospitals, routes of transport, etc.) or are used to store or process toxic substances. The psychological effects of extreme events should also not be underestimated. The people affected are often traumatised after the event.

In comparison to the heat-wave summer of 2003, floods, landslides and storms cause less deaths (20 deaths in the year 2000 caused by landslides/floods). On the other hand, the loss of years of life is within the same order of magnitude in both cases, since heat waves mainly affect the elderly population, while floods, landslides and storms often also claim the lives of younger people.

Water pollution due to floods

In the case of floods, sewage plants and sewers may overflow and sewage or toxic substances may endanger the health of the population. However, the risk of drinking water contamination is small in Switzerland. The drinking water predominantly comes from ground or spring water (see Water management chapter). It does happen that drinking water is contaminated locally by floods, as the floods in autumn 2005 showed. However, the monitoring of drinking water works so well that the population can be informed in time and the water supply secured by other sources until the original supply is restored. Up to now, there have been very few cases of health problems caused by contaminated drinking water and this is unlikely to change with climate change before 2050.

Figure 2: Mudslide in autumn 2000 in Gondo, Valais, after heavy precipitation.
(Source: Union of cantonal fire insurances, Commission for natural hazard damage prevention. VKF, Bern)

Uncertainties and measures

With the increasing number of extreme events, the risk for humans rises as well. However, the extent to which the frequency and intensity of extreme events will increase due to climate change is hard to estimate, and is at this time largely unknown.

People are able to protect themselves against the effects of extreme events up to a certain point by taking appropriate measures. Avalanche barriers in alpine valleys and flood protection measures along rivers are examples of successful preventive measures. However, even the most modern infrastructure does not offer complete protection. In some places, society therefore needs to limit itself to defining endangered settlements (risk maps), mitigating the negative effects through early warning and measures, and providing quick assistance for victims.[7] The correct individual behaviour of the population in the event of a warnings is very important.

4. Food poisoning

As a result of climate change, the danger of food poisoning due to spoilt food and of diseases spread by food (e.g. salmonella) will increase. This risk is particularly high during heat waves and primarily affects private households, where knowledge about the proper handling of perishable food is limited.

Food perishes more quickly at higher temperatures and in addition, the germs multiple faster than at lower temperatures. Furthermore, germs survive longer in warmer surroundings. Global warming therefore enhances the danger of food poisoning and of diseases spread by food (e.g. salmonella or coliform bacteria).

The risk of spoilt food and germs in food is particularly high in private households where the know-how about the proper handling of food during extended hot periods is often lacking. A relationship between temperature and salmonella diseases has for example been ascertained.

Measures

Food inspection and the controls in the food industry are sufficient to cope with the effects of global warming to 2050. However, the demands on the food industry regarding compliance with hygiene regulations and the necessary efforts will rise. Important measures for private households are primarily to inform the population about the risks of food-borne diseases in the warm season, and to make adequate recommendations for the proper storage of food.

5. Respiratory diseases and allergies

Ozone concentrations could increase in summer due to global warming. Furthermore, the pollen season could get longer. Both developments would result in an increase in respiratory diseases.

Ozone

Under the same initial conditions, higher temperatures lead to higher ozone concentrations. The effects of the heat-wave summer of 2003 on ozone levels are clearly discernible in fig. 3. Ozone partly accumulates during prolonged warm, dry spells. Ozone can, at least temporarily, cause respiratory problems, reduce lung functioning and raise the acute death rate.

Global warming and the more frequent occurrence of heat waves mean favourable conditions for high ozone concentrations. However, for ozone formation and the long-term consequences for respiratory diseases, primary pollutants such as nitrogen dioxide (NO_2), volatile organic compounds (VOC) or particulate matter are more important.

Measures

Ozone concentrations, in particular problematic peak concentrations, may be reduced by cutting the emissions of primary pollutants (nitrogen oxides, VOC). The population should be quickly informed in case of high ozone levels. In the last ten years, ozone information systems have already been established in many regions.

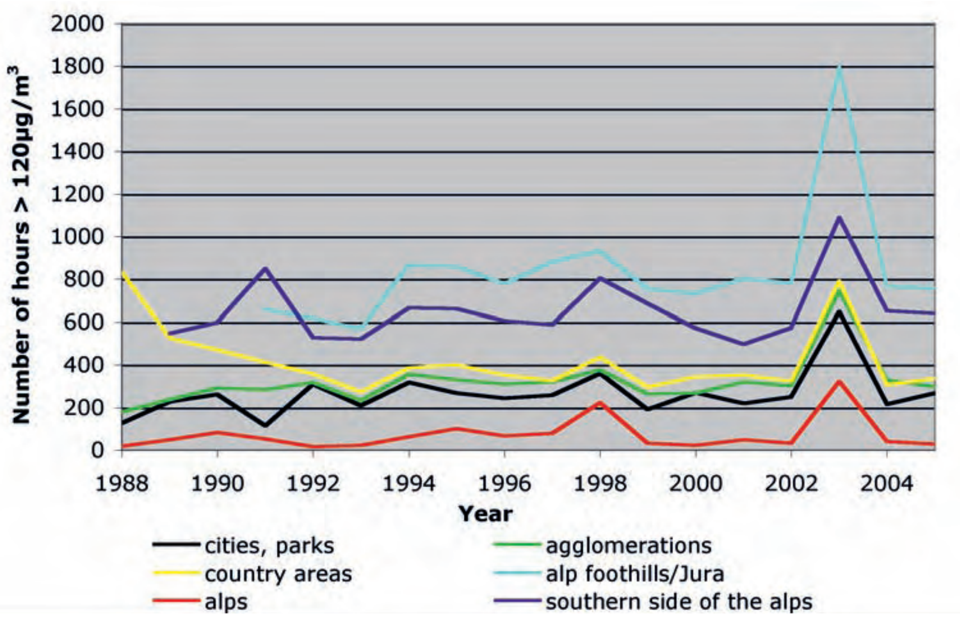


Figure 3: Number of hours per year with ozone concentrations over 120 µg/m3 at NABEL measuring stations in cities/parks (black), agglomerations (green), country areas (yellow), Alp foothills/Jura (blue), Alps (red) and the southern side of the Alps (purple). (Source: NABEL, BAFU and Empa)

Pollen

Temperature and precipitation are important factors affecting the composition of the vegetation and the length of the growing season. However, the growing season and bloom time are also strongly influenced by land use and by the CO_2 concentration of the air (see Land ecosystems and Agriculture chapters).

Warming will alter the pollen production of plants. In the last decades, the pollen season has already shifted towards an earlier occurrence in the year. There is also evidence that the pollen season of grasses has become slightly longer. In contrast, a significant change in pollen amounts has not yet been detected. The pollen season, and therefore the duration of exposure for people with allergies, is likely to get longer in the future as a result of global warming. Whether the future temperature rise will result in higher pollen concentrations is unclear. Pollen production could also increase due to the higher CO_2 concentration.

The increase in ambrosia pollen that is currently being observed can be attributed to the increased spread of this plant species. Ambrosia has a high allergy potential. Its spread and the spread of other Mediterranean plants with high allergy potential (Parietaria, Cupressaceae, Olea, Platanus, Chenopodiaceae), which are favoured by global warming, could result in an increase in allergic diseases. However, the consequences of these changes for respiratory diseases is unclear, e.g. whether more people will be affected by allergies.

Uncertainties and measures

Up to now, there have been almost only retrospective studies on the spread of pollen allergies and the possible connection with climatic parameters, while models of future development are missing. Many relationships are unclear, in particular the reasons for the triggering of allergies. Likewise, the question of the possible impact of warming on the allergen content of plants also remains unanswered.

The spread of pollen cannot be prevented. However, it is possible to take measures against the spread of new allergenic plants, such as ambrosia, or to refrain from cultivating plants with a high allergy potential like, for instance, olive trees. Informing the population about current pollen concentrations is an important measure, and one that is already well organised and assured. People with allergies can get the information required from different media.

6. Vector-borne diseases

Exotic diseases

The distribution of vector-borne diseases will be influenced by climate change. In Switzerland, the spread of exotic diseases that only affect humans, like malaria or dengue fever, is rather unlikely. On the other hand, diseases that are transmitted from animals to humans are on the advance (e.g. West Nile fever).

The distribution of exotic diseases not only depends on the temperature but is also significantly influenced by the vegetation and sanitary conditions. Thus, for example, malaria was eradicated in Central Europe mainly due to the draining of marshes and the improvement of hygiene. There are, however, many complex processes influencing the spread of these diseases, such as gene mutations in vectors and disease-causing organisms or temperature thresholds, which make the projection of the future distribution difficult.
Climate change can affect the distribution of vector-borne diseases (diseases where the causative organism is transmitted by so-called vectors, i.e. other living organisms such as insects) in different ways: mosquitoes can mutate in such a way that they become new vectors; the reproduction of vectors may be facilitated; storms may favour the transport of vectors or improve the habitat of vectors. With changing climatic conditions, the possibility cannot be excluded that a few disease-causing organisms may affect species, including humans, that have not before been affected. In some cases, higher temperatures can also reduce the spread of vectors, e.g., schistosomiasis).

As a result of climate change, it is possible that the regional distribution and the seasonal occurrence of vector-borne diseases may change.[8] The northward spread of dengue fever in Africa and the occurrence of West Nile fever in the Camargue has already been observed. In Switzerland, however, the spread of tropical diseases (malaria, dengue fever) is rather unlikely. Nonetheless, there may be a slight increase in previously rare infections (e.g. airport malaria), as the vectors are able to survive longer with warmer temperatures in our latitudes. Likewise, the larger global distribution of vectors and the increasing mobility in the course of globalisation will result in more “imports”.
Some agents of animal diseases, such as e.g. heartworm, piroplasms and leishmania, are already communicable to humans (zoonoses) or may become so. Amongst the animals of Switzerland, as well as of neighbouring countries, a trend towards more numerous outbreaks of exotic vector-borne diseases can be observed. Examples for this are anaplasmosis in Switzerland in 2002 and bluetongue disease in Italy and France.

Measures

It is necessary to observe and monitor the spread of animal diseases. Early warning of host changes will be important for preventive measures and to inform the population. Vigilance with respect to newly emerging diseases is one of the goals of the Federal Veterinary Office (FVO).

Tick-borne diseases

How the frequency of tick-borne diseases will change is not clear. The distribution of ticks is limited by a low temperature threshold; in warmer regions the occurrence of ticks is limited by aridity. A temperature increase influences the period of activity of ticks, as well as possibly the infection rate and the leisure time activities of people. Currently, an increase in tick-borne encephalitis can be observed.

Climate change may have a stronger impact on the distribution of already domestic diseases, such as the tick-borne borreliosis (bacterial disease) and encephalitis (acute inflammation of the brain), than on exotic diseases. In Switzerland, encephalitis cases have become more numerous in the last decades (see fig. 4). However, a direct relationship between the annual fluctuations of cases and temperature is not apparent. In Austria, encephalitis cases have decreased within the last years thanks to the thorough immunisation program.
The distribution of tick-borne diseases depends on the distribution of ticks, as well as on the distribution of the borreliosis bacteria and the tick-borne encephalitis virus. Both are influenced by climatic factors. In Switzerland, the distribution of ticks is limited amongst other things by the low temperature threshold. Milder winters favour the chance of survival of ticks and their host animals, and enable ticks to advance to higher elevations. Rising temperatures influence the spread of disease-causing organisms. Thus, a decline is expected in the incidence of encephalitis in Switzerland, due to the rise in summer temperatures and the decrease in humidity. This decline would not result from the disappearance of ticks from the region but from the interruption of a continued occurrence of the virus within the tick population, and therefore the possible transmission to humans. With a warming of 2 to 3 °C by 2050, Switzerland could become free of tick-borne encephalitis at lower altitudes. However, this prediction is contradictory to what has been observed up to now.
Apart from the distribution of ticks, encephalitis virus and borreliosis bacteria, climate change also affects other factors that are important for the spread of tick-borne diseases. For instance, outdoor temperature strongly influences people's leisure time activities and leisurewear.

Measures

Measures against tick-borne diseases include the observation and monitoring of their distribution. Data on distribution and transmission of tick-borne meningitis are incomplete, which makes monitoring more difficult. Observations of the continuing development could be improved by introducing an obligation to report borreliosis cases.

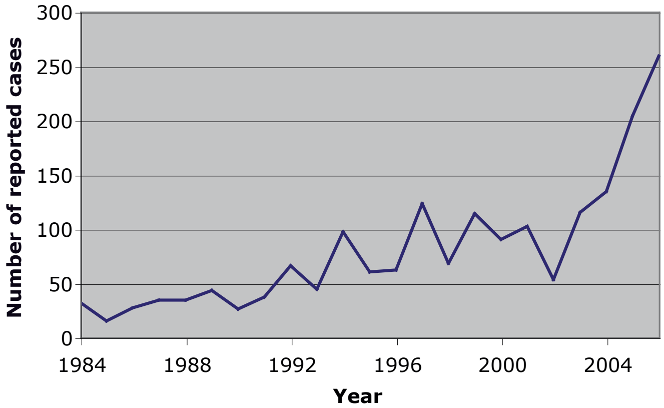


Fig. 4: Number of reported cases of tick-borne encephalitis (acute inflammation of the brain) in Switzerland 1984–2006.
(Data source: Federal Office of Public Health FOPH)

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Tourism

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1. Introduction

Background

Aspects of climate play an important role in tourism. Climate change can directly influence the behaviour of the tourist market, as well as significantly shape the conditions at a holiday destination. In many places, the first effects of warmer temperatures, higher snow lines or more frequent extreme events are already noticeable. However, how tourism will look in the year 2050 depends on numerous additional factors that are not related to climate change. Thus, for instance, globalisation, new technologies, warlike incidents, health risks or other environmental changes very strongly affect travel behaviour. Furthermore, the tourism industry continually adapts to the new challenges. For all these reasons, predictions are difficult. Despite this, an attempt to highlight and discuss the possible effects of climate change on tourism should be made.

Overview

Impact on the different tourism zones

1) City tourism

More frequent extreme weather conditions may increasingly result in adverse health phenomena, such as high ozone or particulate matter concentrations, and thereby harm the attractiveness of cities. On the other hand, hot summers may lead to an increased revival of the public space, whereby more people spend their holidays at home and activities are moved outdoors.

2) Rural tourism

In winter, the rising snow line will mean that some of the ski resorts in the foothills of the Alps cannot be run profitably anymore. In summer, lake regions may profit from excursion tourism by city dwellers, due to higher temperatures.

3) Alpine tourism

Climate change will lead to an increased threat to traffic routes in the alpine region, which will make the accessibility of tourist resorts more difficult. The decreasing snow-reliability and the expected changes in the landscape, in particular due to glacier retreat, will strongly affect the attractiveness of alpine tourism regions. However, heat waves also represent an opportunity for alpine tourism.

Impact on tourism service providers

1) Mountain railways

With climate change, the line of snow-reliability will continue to rise. As a result, the number of ski resorts with unreliable snow conditions will increase considerably. The melting permafrost also poses a costly risk to mountain railways, since the foundations of pylons and stations are frequently anchored in frozen loose rock. Even if warm summers with long periods of fine weather result in an increase in tourism demand, for most mountain railways, winter tourism is critical to their financial survival. Mountain railways at high elevations could possibly profit.

2) Accommodation

The accommodation sector will be affected by climate change, primarily due to the expected changes in winter sports. In areas where snow-reliability decreases, accommodation will suffer from massive slumps. On the other hand, the pressure, particularly on the second-home sector, will increase in snow-reliable and easily accessible areas. In addition to climate change, the hotel sector will also be confronted with numerous unrelated problems (cost pressure, profitability, investment needs, etc.).

3) Outdoor promoters

Glacier retreat changes the alpine landscape and may lead to a loss of appeal, while the melting permafrost will increase the risk of rockfalls and avalanches. The occurrence of more frequent extreme events will change the degree of danger.

Measures

Mitigation and adaptation strategies have to complement one another. Although adaptation measures are absolutely essential, they will only be perceived as credible if tourism, as a contributor to climate change, helps to fight its causes.

- In order to maintain the attractiveness of tourist destinations, tourism managers need to adapt offerings to the new conditions. New concepts or an adequate shift in the focus can help to maintain the attractiveness of a destination.

- Service providers are required to collaborate in order to optimise their offerings, and to work out development and adaptation strategies.

- Tourism providers and managers need to observe climate and landscape changes and consider them in their planning, in order to ensure the future survival of a destination.

- The increasing threat to infrastructure and activity spaces must be met by suitable measures. Spatial planning, development strategies and communication concepts need to take into account the modified risks.

Links to other topics

As a cross-section phenomenon, tourism is linked in numerous ways to other climate-relevant topics. Among these, the following are particularly critical, while others (e.g. agriculture) should not be disregarded either:

Land ecosystems

Landscape changes also mean changes in tourist attractions. The loss of protective capacity particularly affects alpine tourism.

Water management

Water shortage has an impact on passenger boating and water-related tourist activities. In winter, possible shortages in water supply may affect snowmaking.

Health

New health risks may increase the demand for wellness. Rural or alpine areas might become more attractive as recreational areas.

Insurance

Insurance rates for tourist businesses will become more expensive due to the increased danger risk of more frequent natural hazards.

Buildings/infrastructure

The mobility and travel behaviour is a determining factor for the building and infrastructure sector. Changes in the development of tourism affect building activities (second homes, facilities, etc.). The protection and maintenance of traffic routes using structural measures are very important to tourism.

2. Change in offerings and demand due to climate

With climate change, the climatic and environmental conditions change not only in Switzerland but also in the country of origin. This leads to a change in offerings and demand, which may result in a shift in tourist flow, also within Switzerland.

Countries and regions of origin

Changes in international tourist flow are to be expected due to climate change. While certain areas will lose attractiveness from a climatic perspective, for others new chances will arise. For the foreign tourist flow in Switzerland, the conditions in the countries of origin are of great relevance. If the temperatures rise strongly in the Mediterranean region as a result of climate change, the demand for holidays in the mountains will be favoured. In summer, holidays in the alpine area may profit from hot temperatures in Europe.

Shifts may also take place within Switzerland. Thus, for instance, it is important to ski resorts whether there is snow in the midlands and thereby whether the need to drive to the mountains will increase. Again, in summer, hot temperatures in the lowlands may motivate its inhabitants to seek alpine coolness.

Altogether, it can be assumed that the needs, demands and expectations of tourists alter with climate change. Travel preferences may change in time as well as place.

Target countries and destinations

Climate change not only means warmer temperatures and a changed precipitation regime but also a change in environmental conditions. Environmental and landscape changes will have a direct impact on tourism, even if the effects are hard to predict.

Climate change also affects what a destination has to offer indirectly. The change in climatic conditions means that the opportunities for certain activities at a destination change. Tourism service providers need to adapt insurance and investment strategies to the new conditions, which in turn affect the labour market and value creation.

Figure 1: Glacier retreat, which had already begun in the 19th century, had at first primarily natural causes. Enhanced global warming caused by human impact has dominated glacier retreat in the Alps since the mid-20th century.
a) Lower Grindelwald glacier in 1858 (photographed by Frédéric Martens, 1809–1875, Alpine Club Library London; photograph: Heinz J. Zumbühl)
b) Lower Grindelwald glacier in 1974 (photograph: Heinz J. Zumbühl). The arrow, as well as the small embedded picture, show the location and state of the glacier front in 2006 (photograph: Samuel U. Nussbaumer)

3. Impact of climate change on natural tourism offerings

Climate change has far-reaching impacts on tourism, due to the decreasing snow-reliability, changed landscape and increased threat to infrastructure (traffic routes, transport facilities).

Decreasing snow-reliability

By 2050, the snow line is expected to have risen by up to 350 m. Warmer temperatures will shorten the duration of snow cover, as well as reduce the number of days with snowfall at lower elevations. For many skiing regions, this is the most direct and greatest challenge. In particular, stations at lower elevations will hardly have enough snow anymore by 2050 to continue to operate skiing facilities (see section 4). However, the expected increase in winter precipitation (see Background chapter) will mean an increase in snow quantity at elevations above 2000 m, which could possibly increase the danger of avalanches.

Glacier retreat

Due to the strong glacier retreat (fig. 1), the alpine landscape will change considerably and with it possibly also its attractiveness to tourists. By 2050, the glaciated area in the Alps will probably have decreased by about three-quarters in comparison to the reference period 1971–1990 (see Background chapter, section 3). Some tourist locations are already in trouble, particularly if the glaciers are used for activities like skiing, glacier hiking or ice-tubing. The maintenance of glacier grottoes is becoming increasingly difficult and expensive. Measures to prevent melting, such as the covering of glacier areas with protective sheets, will not be able to stop the retreat.

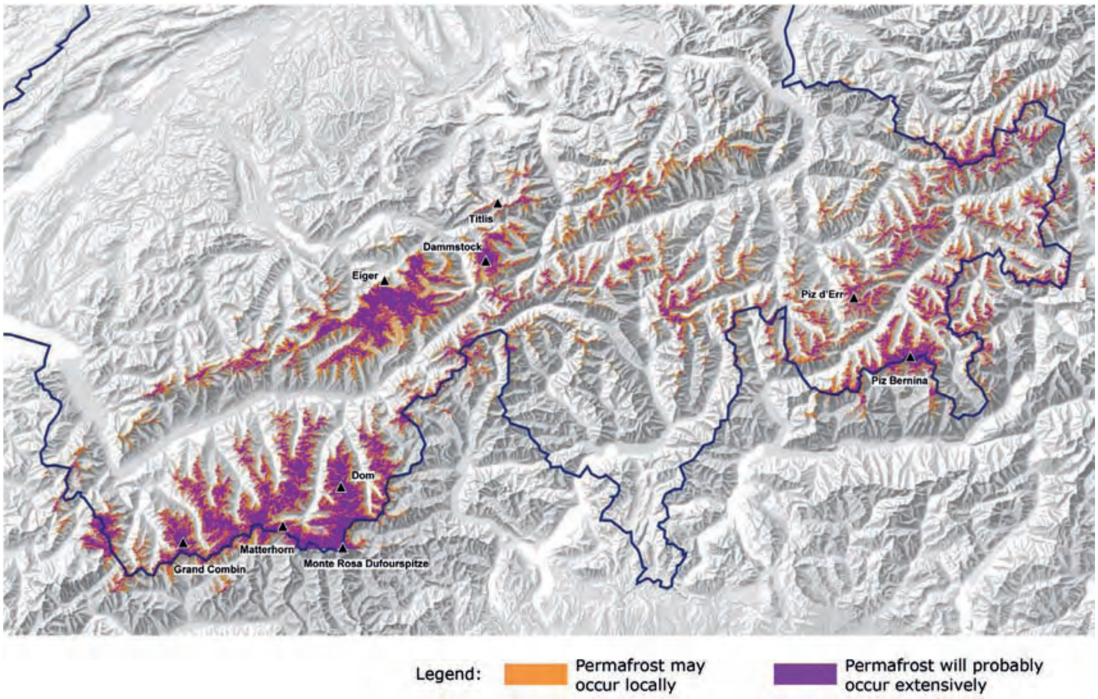


Figure 2: Potential permafrost distribution based on modelling using DHM25. About 15% of the Swiss alpine area, or 4 to 6% of the total land area, are in permafrost territory.
(Source: Federal Office for the Environment FOEN 7/06)

Melting permafrost

Melting permafrost destabilises ground conditions. Most affected are the Engadine, Valais, Bernese Alps and Tödi area (fig. 2). Problems should be particularly expected where infrastructure, such as avalanche barriers or pylons of mountain railways, is anchored in the permafrost ground.[1] The danger of rockfall and landslides will also be increased by the melting permafrost. Alpinism (walking, hiking and rock climbing routes) is especially affected by the danger of rockfall. Settlements are hardly at risk from these processes.

Extreme events

Much points to the fact that extreme weather events will increase. Since tourism largely depends on the weather, the consequences are considerable:

Heat waves

Heat waves strongly affect the hydrological cycle, as well as the landscape and vegetation. However, more frequent heat waves also offer an opportunity for alpine tourism: The slightly cooler mountain air (summer retreat) may make the Alps a more interesting holiday destination, in particular if competing destinations like the Mediterranean lose in attractiveness due to rising temperatures. For example, the heat-wave summer of 2003 stimulated day trips to the Alps.

Dry spells

Lower precipitation in summer, in combination with higher temperatures, results in more frequent dry spells. From a tourist perspective, activities like bathing in rivers and lakes, fishing, kayaking or river rafting, as well as passenger boating may be affected. If the reservoirs are not sufficiently filled by the start of the winter season, water shortage may cause supply problems for snowmaking facilities.

Precipitation extremes

The expected increase in precipitation extremes will have an impact on the frequency and intensity of floods, landslides, mudflows and rockfalls (see fig. 3). Many traffic routes are exposed to such risks. If roads had to be blocked more frequently in the future, this would have far-reaching consequences, since the accessibility of a place is central from a tourism perspective. This means increasing costs to ensure security for tourism service providers.

Landscape changes

Warmer temperatures will particularly leave a trace in high alpine landscapes. Many landscape phenomena, such as glaciers, vegetation or terrain, will experience considerable changes. Flora and fauna will adapt to the new conditions,

Figure 3: Two mudslides occurred in Brienz during the storm in summer 2005 (photo of the mudslide at Glyssibach). In addition to financial losses, there were two human deaths.
(Source: Swiss Air Force)

although it should be noted that certain natural processes, like forest regrowth, only proceed very slowly and thus take place with a considerable time lag (see Land ecosystems chapter, section 2). These changes may represent an opportunity as well as a risk to tourism.

Changes in attractiveness in Val Morteratsch and Val Roseg near Pontresina (2005–2100)

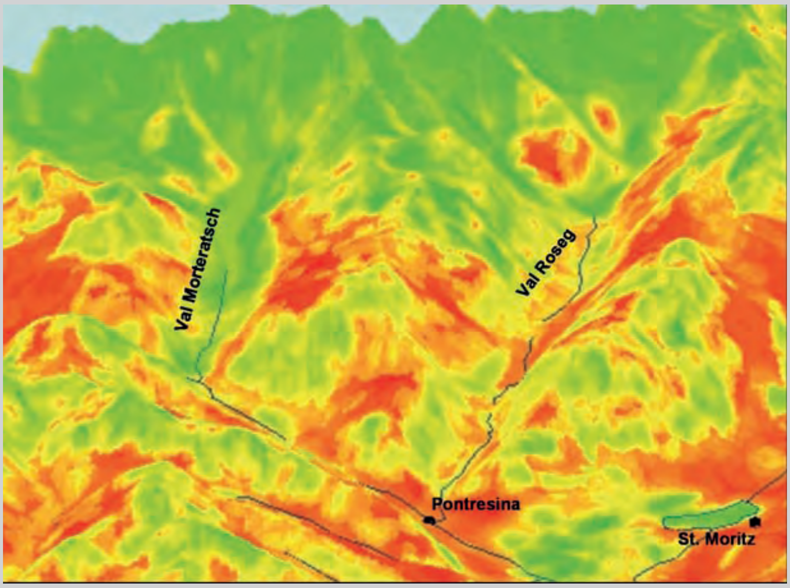
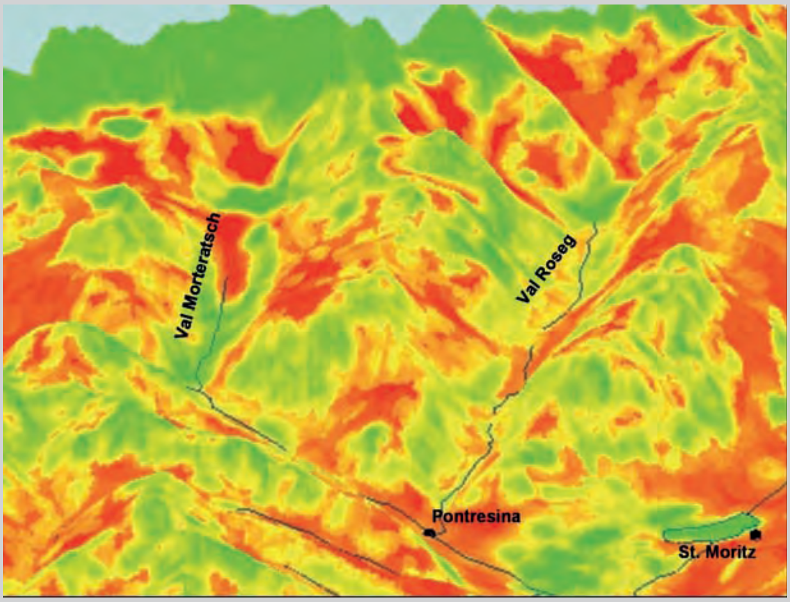


Figure 4: The GISALP-calculated landscape attractiveness in 2005 (4a, top) and 2100 (4b, bottom) after a climate warming of +3 °C.

a) Glacier areas, lakes and diversified areas with good visibility have a higher calculated landscape attractiveness (green). Settlement areas and areas with little variety of form and less visibility are considered less attractive according to the calculation model (red).



b) Debris dominates in the areas of Val Roseg and Val Morteratsch from which the glaciers have retreated. Two new lakes in the forefield of the Morteratsch glacier represent new landscape attractions. Thus, landscape attractiveness increases in certain areas, even though overall it decreases considerably in the high mountains.

(Graphics: Ch. Rothenbühler, Academia Engiadina)

Landscape attractiveness of the high mountains generally decreases as a result of debris areas, which are mainly due to melting glaciers. Although areas with an increased landscape attractiveness may also arise, they are less numerous.

4. Impact of climate change on tourism in Switzerland

The tourism sector represents 3.4% of the GDP and is thus of great importance to Switzerland. Based on the expected effects of climate change and the economic vulnerability of some destinations, the most important changes are expected in alpine tourism.

Tourism in Switzerland

It is beyond dispute that the tourism sector represents an important branch of Swiss economy. The direct gross value added of tourism (at current prices, 1998) amounts to 12.9 billion CHF, which corresponds to 3.4% of the GDP. The directly associated, full-time equivalent (FTE) employment amounts to 165,500 employees and corresponds to a share of 5.2% of the tourism sector in the entire full-time equivalent employment in Switzerland. The distinctly higher share in comparison to the gross value added is due to the lower level of labour productivity. The share of the most important economic sectors in the tourism value added is divided as follows: accommodation (31%), restaurants (14%), passenger transport (20%) and travel agencies/tour operators (9%).[2]

In 2005, hotels and health resorts recorded 13.8 million arrivals and 32.9 million overnight stays. In hotel and non-hotel business, a total of 65 million overnight stays were registered. 56% of the bookings were Swiss guests. The largest proportion of guests came from Germany (18%), Great Britain (4%), the Netherlands (4%), France (3%) and the USA (3%).

The winter season accounts for 46% of overnight stays and the summer season for 54%. However, the winter season has a considerably higher turnover due to winter sports.[3]

Impact on tourism zones

Basically, three tourism zones can be distinguished in Switzerland: city, rural and alpine. Tourism statistics report mountain health resorts (located above 1000 m a.s.l.), lake zones (locations bordering lakes) and big cities (Basel, Berne, Geneva, Lausanne and Zurich) separately. Mountain health resorts account for 39.1% of the overnight stays in hotels, lake zones for 19.9% and big cities for 17.6% (2003). The remaining 23.4% fall to the other, more rural areas. 60.9% of the hotel overnight stays are generated in the alpine area, 34.6% in the midlands and 4.8% in the Jura.[3] In the description of possible impacts of climate change on the tourism zones in Switzerland, the focus is on alpine tourism.

City tourism

In 2003, the five biggest cities generated almost one fifth of overnight stays in hotels in Switzerland.[3] The proportion of foreign guests amounts to 76.4%. In cities, short stay and cultural tourism play an important role in addition to business tourism. Due to their man-made environment, cities are less vulnerable to visible effects of climate change. Nevertheless, climate change will be noticeable in cities.

Cities are not immune to natural hazards, in particular floods, though entire cities are hardly ever affected. As a rule, such events are perceived to be less dangerous in cities than in rural areas. The occurrence of more frequent extreme weather conditions may lead to an increase in adverse health phenomena, such as high concentrations of ozone or particulate matter. Due to high temperatures and more frequent heat waves, city dwellers may go on excursions to the country or to the mountains more frequently.

On the other hand, hot summers may cause city dwellers to move their activities outdoor more often. Public spaces are thereby revitalised and the city image becomes more attractive (mediterranisation). People perhaps increasingly spend their summer holidays at home or shift their main holidays to the low or winter season. A temperature rise in Swiss cities will tend to have a positive effect on the travel patterns of foreign visitors.

Rural tourism

The midlands register 34.6% of all hotel overnight stays, although a large part of them are in cities.[3] Rural tourism in the midlands can be subdivided into the lake regions and the pre-alpine areas. The natural scenery in the midlands is primarily shaped by agriculture, so that the changes are not expected to be as strong as in the high mountains. As a result of their proximity to large agglomerations, the lake regions might profit at warmer temperatures from the increase in day-trip tourism.

The rising snow line will be a great challenge to skiing regions in the foothills of the Alps. Resorts that already have little snow today will not be able to be run profitably in the future. They will have to orient themselves to new offerings. In summer, on the other hand, they might benefit from the increase in short and day-trip excursions by city dwellers.

Alpine tourism

In many places in the Swiss Alps, tourism is the most important employer. In some tourist destinations, the value added of tourism amounts to more than 80% of the regional GDP. The enormous economic significance also means a high vulnerability of this economic sector in the alpine region. Some consequences of climate change are already noticeable today (see figs. 5 and 6) and will pose a great challenge to tourism in the alpine regions in the future. Changed conditions in the original (natural factors, general infrastructure) and the derived offerings (tourist infrastructure and attractions) will affect all service providers of a destination.[4]

Where the general infrastructure of alpine holiday destinations is concerned, an increase in

Figure 5 (left): Slope at Mettenberg near Grindelwald after a landslide. The hut (red circle) was also destroyed by the slide.

(Source: H.R. Keusen, Geotest AG)

Fig. 6 (bottom): Tourism use in a precarious location. The hut at Mettenberg (see fig. 5) is no longer standing. Photo: summer 2005.

(Source: H.R. Keusen, Geotest AG)

Fig. 7: Engelberg Central Railway, storm in 2005. (Source: Swiss Air Force)

interrupted or blocked traffic routes is to be anticipated (see fig. 7). Thus, accessibility, which is central to tourism, could be significantly impaired. The threat to sensitive traffic routes could increase and so could the accident risk. The protection of traffic routes and other infrastructure against natural hazards is complex and expensive. In comparison to incidents (e.g. cyclones) at destinations abroad, the natural hazards in Switzerland, which are mostly localised (avalanches, mudflows), are more easily predicted. In addition, more substantial means for protection and coping with incidents are available, so that this threat to security will not mean a comparative disadvantage for the alpine region.

The changes in the natural landscape that are expected due to climate change will strongly influence the attractiveness of a destination. The tourist offerings will change too. In the Alps, the mountain railways and transportation businesses are expected to feel the effects of climate change the most. However, the accommodation sector (hotel and non-hotel accommodation) and the broader tourist attractions (outdoor activities) will also be directly or indirectly affected by the effects.

Impact on tourism service providers

Mountain railways

The economic miracle of the post-war period and the development of efficient aerial tramways and cable cars turned skiing into a national sport. There are about 1790 mountain railways in Switzerland today: 12 cog railways, 58 funiculars, 216 aerial tramways, 120 cable cars, 314 chair lifts and 1070 ski lifts. The mountain railways hold a central position in the value added chain of tourism. Funiculars are often the determining factor in tourist destinations and therefore indirectly induce value added to other service providers as well (e.g. hotel sector, gastronomy, retail trade). The mountain railways offer more than 4700 full-time positions, which are again split into 11,000 jobs (full-time and part-time positions).

The winters with little snow since the 80s have resulted in sharp declines for the mountain railways in certain areas.[5] The rising snow line will continue to represent a great challenge to many mountain railway operators in the future. In particular, skiing regions at lower elevations will tend to become less snow-reliable. A shift in the line of snow-reliability considerably increases the proportion of skiing regions in Switzerland that are not snow-reliable. According to a study by the OECD, 97% of the skiing regions in Switzerland are currently considered to be snow-reliable,[6] where snow-reliability means that in 7 out of 10 winters between 1 December and 15 April, there is snow cover adequate for snow sports of at least 30 cm on at least 100 days. The study considers skiing regions offering at least three

Possibilities for snowmaking

With rising snow lines and the simultaneous rise in expectations of snow-reliable holiday destinations by winter sportspeople, many winter sport regions are increasingly investing in artificial snowmaking. Snowmaking requires that certain meteorological conditions are fulfilled. It only works efficiently if air temperatures are 2 °C or below,[6] humidity is less than 80% and water temperature is a maximum of 2 °C. In order to make snow at higher temperatures, snow additives are often employed. The energy and water consumption of the machines is relatively high but depends on the technical system selected, the location, water supply and climatic conditions. In addition, high costs arise from infrastructure and operation of the machines.[8] Technical measures will be able to replace the lack of snow only to a limited extent and snowmaking will be possible less often with warmer temperatures. While the effect on the energy market is hard to predict, it can be assumed that water resources will become more valuable. Water shortage may become a problem for winter sport locations that strongly depend on snowmaking. Snow conditions will make it necessary to invest further in snowmaking facilities, as well as in reservoirs and the maintenance of drainage systems. For mountain railways, snow shortage and an increased danger potential mean strongly rising costs. With artificial snowmaking, these costs cannot entirely be shifted onto the price, since snow-reliability is similar to an insurance benefit, which only offsets a comparative disadvantage and does not represent an additional benefit.

transportation facilities and 5 km slope length. Skiing regions at lower elevations in the Jura are excluded. Based on these criteria, the study includes a smaller number of skiing regions in comparison to previous studies.[5,7] The skiing regions taken into account are generally located at higher elevations and are therefore less vulnerable to changes in snow-reliability.

With a shift in the line of snow-reliability by 300 m, as is expected by 2050, only 79% of the skiing regions would still be snow-reliable. In particular, ski tourism in the Vaud and Fribourg Alps, in Ticino, and in Central and Eastern Switzerland is at risk, where only 50 to 60% of the skiing regions will be snow-reliable by the mid-21st century. The skiing regions in the Valais and in Grisons will be less affected (see table 1). In comparison to Switzerland, the effects of climate change will be even more drastic in the skiing regions of the Alpine countries France, Italy, Austria and Germany.[6]

Climate change will not only affect snow-reliability but also the demand for winter sport offerings. In the medium term, the interest of the younger generation for skiing sport may decrease, since children will lack the opportunity to learn skiing locally in early life. In Switzerland, the number of skiers is already stagnating, although this is only marginally related to climate change.

Table 1: Snow-reliability in Swiss skiing regions under current and future climatic conditions. (Source: Abegg et al. 2007)[6]

Region	Number of skiing regions	Snow-reliability			
		today	+1°C[a)]	+2 °C[a)]	+4 °C[a)]
Vaud and Fribourg Alps	17	100%	65%	53%	6%
Bernese Oberland	26	96%	85%	62%	12%
Central Switzerland	20	90%	75%	55%	20%
Eastern Switzerland	12	83%	58%	58%	8%
Grisons	36	100%	97%	97%	83%
Valais	49	100%	100%	100%	80%
Ticino	4	100%	75%	50%	0%
Switzerland	164	97%	87%	79%	49%

a) time horizon: +1 °C: ca. 2020s; +2 °C: ca. 2050; +4 °C: towards the end of the century

Glacier retreat not only means the loss of an important attraction to many winter sport regions but also, particularly in summer, a restriction on offerings of glacier activities. The melting permafrost poses a further threat to certain mountain railways. Infrastructure that is anchored in the permafrost ground may be destabilised by variations in temperature. Since the foundations of pylons and stations of mountain railways as well as of avalanche barriers are anchored in the frozen loose rock, the necessity for costly rebuilding of the foundations increases. The melting permafrost also means an increasing risk of rockfall, landslides and mudflows, which again results in higher investments in safety and may lead to an increase in service interruptions.

In warm summers with long periods of fine weather, the mountain railways may profit from the increase in mobility intensive day-trip and short-stay tourism. With appropriate adjustments, particular sports like mountain biking that are of relevance to mountain railways could gain in importance. Even new offerings for activities could be developed. However, only few mountain railways succeed in making summer business profitable and they cannot survive without a "good" winter.

Accommodation

In recent years, the number of hotels has decreased from 6300 (1992) to 5600 (2003). The number of beds has decreased only slightly within the same time period from 261,900 to 258,700. Even if certain concentration processes are under way, small hotels still dominate in Switzerland. The economic situation of the Swiss hotel business is not a pretty picture. Often the profitability is insufficient, the capital gearing is too high and the investment needs are large. The number of overnight stays in hotels also fell by about 14% between 1992 and 2003, from 36 to 31 million. While the number of guest arrivals increased slightly within this period, the average duration of stay decreased strongly. The booming second-home tourism became a primary competitor to the hotel business in the Alps. The manifold problems of the Swiss hotel business are in the minority of cases directly related to climate change.

While the hotel business offers about 260,000 beds, holiday flats and second homes provide about 1.2 million beds. A further 430,000 beds and sleeping places are offered by youth hostels, group accommodation and campgrounds. The alpine area is a popular region for second homes and holiday flats. The number of second homes has increased enormously in recent years, which has brought with it various problems (infrastructure geared to peak loads, urban sprawl, poor capacity utilisation, rising prices for locals, etc.). About two thirds of the second homes and holiday flats in Switzerland are occupied only a few weeks every year but are heated the entire winter. They therefore contribute considerably to CO_2 emissions. In spite of the expected decrease in heating degree days from 98 (2004) to 85 (2050), energy consumption will continue to rise. In addition, there will be increasing demand for cooling in summer (see Energy chapter, section 2).

Climate change will affect the accommodation sector, in particular because of the changes in winter sports. In locations where winter sports are no longer a catalyst, the accommodation sector will experience massive slumps in demand. On the other hand, settlement pressure and thus mobility as well will increase at prime locations. Since the Lex Friedrich (consent to property purchase by foreigners) will be abolished, some regions are trying to restrict the building of new flats using new measures. The dynamics of the second-home market are shaped by many factors, of which until now climate has played a minor role.

Changes in the tourist attractions and in the landscape will affect the attractiveness of a destination and therefore influence property prices. The potential for conflicts in new land development will grow due to the increased risk from natural hazards. The pressure on snow-reliable and easily accessible regions will increase. Insurance premiums and bank loans will tend to get more expensive because of the increased risks[9] (see Insurance chapter, section 4). Altogether, the added value of tourism will decrease at certain places despite an increasing number of tourist beds. If tourist flow shifts seasonally and spatially, the accommodation sector will feel the effects, although not to the same extent as businesses depending on daily tourism. Where the attractive winter business with high value added potential collapses, a lot of hotels will have to close down.

Outdoor promoters

Hiking and alpinism have been popular for many years and are currently booming. Furthermore, with carving, snowboarding, snowshoeing, mountain biking, Nordic walking, paragliding etc., new outdoor sports are continually being added.

The alpine landscape is strongly shaped by climate. Climate change not only means a loss of appeal but also increases the risk of rock slides and rockfalls due to melting permafrost. More numerous extreme events also have an impact on the degree of danger on waterways, which may be of relevance to sports like kayaking or canoeing. The growing number of extreme events increases the risk for all outdoor sports. At the same time, warmer summers with low rainfall increase the attractiveness for hiking, as well as for bathing and other water-related activities, such as kitesurfing.

Outdoor promoters will need to respond to the changing natural conditions by adjusting their offerings. Consideration of the risks and corresponding investments in safety will gain in importance.

5. Strategies and measures

Tourism needs to adapt to the effects of climate change. The adaptation and diversification of offerings, as well as technical and organisational measures may mitigate the negative effects and provide new chances. However, as a co-contributor to climate change, tourism is at the same time required to reduce greenhouse gas emissions.

The tourism sector is not only affected by rising temperatures but is also an important co-contributor to climate change. Individual holiday traffic in particular contributes substantially to the emission of climate-relevant gas emissions. As a result of improved development, increasing motorisation and willingness to travel after the Second World War, traffic in the Alps has strongly increased. Similarly, the mobility-intensive short-stay and second-home tourism has grown. In addition to traffic emissions, heating and, increasingly, cooling energy of tourist accommodation also have a share in the greenhouse gas emissions caused by tourism. In particular, second homes are of significance.

Thus, measures to reduce emissions must have priority: promotion of public transport, consistent application of the "polluter pays" principle (e.g. to encourage low-pollution cars), improved traffic management, reduction of emissions generated by heating facilities of tourist accommodation, compensation of climate-effective emissions etc. At the same time, tourism needs to adapt to the changed conditions due to climate change.

Promotion of innovation and diversification

Tourism managers are requested to adapt their offerings to the new conditions and to work out coordinated and comprehensive concepts, since every service provider contributes to the attractiveness of a destination:

- Diversify the offerings, adapt to new tourist activities and shift the focus
- Extend the season with appropriate offerings (temporal expansion)
- Specifically further regions at higher elevations that have already been developed, in order to enhance snow-reliability (spatial expansion)
- Broaden the understanding of wellness with regard to air, elevation, light, nutrition and culture (alpine wellness)
- Actively retreat from (skiing) tourism, for instance by closure compensation (managed retreat); diversify into other economic sectors

Reinforcement of danger prevention and technical measures

Infrastructure and activity areas need to be protected from new and partly increasing risks:

- Support biological measures such as afforestation
- Guide landscape changes, set up protected zones and green belts
- Renovate the foundations of facilities and protect them from natural hazards
- Protect infrastructure from avalanches, rockfalls, landslides and mudflows
- Enhance the effectiveness of snow machines
- Target slopes for snowmaking, construct storage lakes, cover glaciers if applicable, etc.

Reduction of risks by organisational measures

With regard to new challenges, co-operation or fusion between service providers should be intensified and new adaptation strategies developed:

- Merge mountain railway companies and carry out compensated closures in order to optimise skiing regions, merge skiing regions
- Work out destination development strategies collectively
- Set up and adapt hazard zone plans (land-use planning measures)
- Develop evacuation and communication concepts
- Inform the population and tourists openly and create a public awareness for climate issues

Intensification of science and closing of knowledge gaps

Many possible effects and, in particular, the interactions between various factors relevant to tourism are not clear as yet. The developments should be monitored and new insights considered:

- Observe developments locally and identify the need for action early
- Monitor changes in the travel behaviour of tourists and adapt offerings accordingly
- Inform the population about weather risks and natural hazards
- Follow and support specific research projects

6. Tourism in the year 2050

Climate change represents a risk and an opportunity at the same time. By suitable adjustment to tourist attractions, core competences can be developed and new guest groups can be appealed to. The concentration of winter sports at top destinations, the promotion of alpine wellness centres and of summer tourism are promising development models.

Revival of the summer retreat

Warmer temperatures and more frequent hot and dry summers will cause a revival of the summer mountain retreat. High temperatures in Southern Europe and in the towns will mean that the Alps are sought after as places of coolness and may profit in comparison to more southerly destinations. The tourist summer season may be extended. In particular, the heavily weather-dependent weekend day-trip and short-stay tourism of the Swiss people will ensure the summer business of tourist locations that have adequately adapted their offerings to the change in travel behaviour.

The heat wave summer of 2003 showed that summer tourism at higher elevations could gain in importance. Places with attractive hiking and bathing opportunities profit from more frequent heat waves and fine weather periods. The proximity to large agglomerations and an adequate adjustment of the offerings is also crucial. New guests may be attracted if destinations in Southern Europe lose in attractiveness because of the heat, and the Alps may become a summer retreat again.

Boom of the new alpine wellness

Health spa tourism played an important role in the Alps at the beginning of the 20th century. Climatotherapy at sanatoriums was recognised for curing respiratory diseases, and spas were very popular. In recent times, health spa tourism has largely been replaced by wellness tourism. While some classic health spas have had to close down in recent years, wellness facilities are increasingly becoming part of to the expected standard in four- and five-star hotels. More and more frequently, classic health spas are being converted into wellness oases and adventure pools.

Health tourism has developed from curing diseases to the preventive, responsible and holistic understanding of body, mind and soul. The new symbiosis is about fitness and well-being. Demographic development means a further increase in the relevance of health to our society. Alpine wellness, which includes the components water, air, elevation, light, nutrition, exercise and culture, will gain in importance. New health hazards (see Health chapter) and the escape from the summer heat may support this trend, so that the appreciation of altitude for recovery will rise again.

Concentration on top winter sports destinations

The conditions aggravated by climate change will lead to a concentration of the viable winter sports resorts. Structural problems and financing difficulties of mountain railways will be intensified by the unfavourable natural conditions at many locations and push forward the change in structure. Lack of snow and water scarcity will be particular bottlenecks for pre-Alp destinations where higher temperatures make it difficult to compensate for the lack of natural snow by artificial snow. Overall, the importance of ski sports will decrease and the choice of winter sport activities will broaden. The costs for artificial snowmaking will rise and the assurance of safety will require financially costly measures. Large businesses that are able to use synergies efficiently will be able to compete most effectively. Small places will focus more on alternative offerings and will specialise in niches in order to gain new markets and win their share of customers.

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Energy

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1. Introduction

Background

Energy consumption drastically increased in Switzerland in the 20th century (fig. 1). Since 1945, it has increased by a factor of eight. The massive rise is due to the increase in the consumption of crude oil combustibles, motor fuels and gas. However, electricity consumption has also continuously increased, while the proportion of coal has strongly decreased. In 2004, energy use was composed of 31.3% motor fuels; 25.7% combustibles; 23.1% electricity; 12.1% gas; and 7.8% other. The following discussions are to be understood against the background of this development.

In the context of climate change, the energy sector is usually discussed as a causal agent. Being the most important source of anthropogenic greenhouse gases, it plays a central role with regard to measures to reduce emissions. In this report, we look at this from a different perspective and consider the effects of climate change on the energy sector. How do warming and the changes in precipitation affect energy production and energy demand?

Energy use for transport is deliberately not taken into consideration. We assume that the transport sector will be less affected by the direct consequences of climate change than by indirect consequences (climate policy).

The effects of climate change on the energy sector will be discussed in more detail for the following topics:

- changes in energy demand (summer, winter)
- established production of electric power (hydropower, nuclear power)
- new renewable energy (wind, wood)
- economic aspects (energy prices, insurance)

This list is not exhaustive but represents a range of interesting and relevant issues. Climate change also affects other important areas of the energy sector, such as security of supply and the supply grid, as well as prospects for other energy sources (geothermal, solar energy, etc.). Within the limited range of topics, the working group did not deal with these areas.

The energy sector is influenced more strongly by other general conditions than by climate change. Thus, for instance, influencing factors such as economic growth, technological development, population growth and the opening of the electricity market have shaped the energy sector in the past and will continue to do so in the future.

Overview

In the future, less heating energy will be used in winter and more cooling energy used in summer due to climate change. There will be a shift

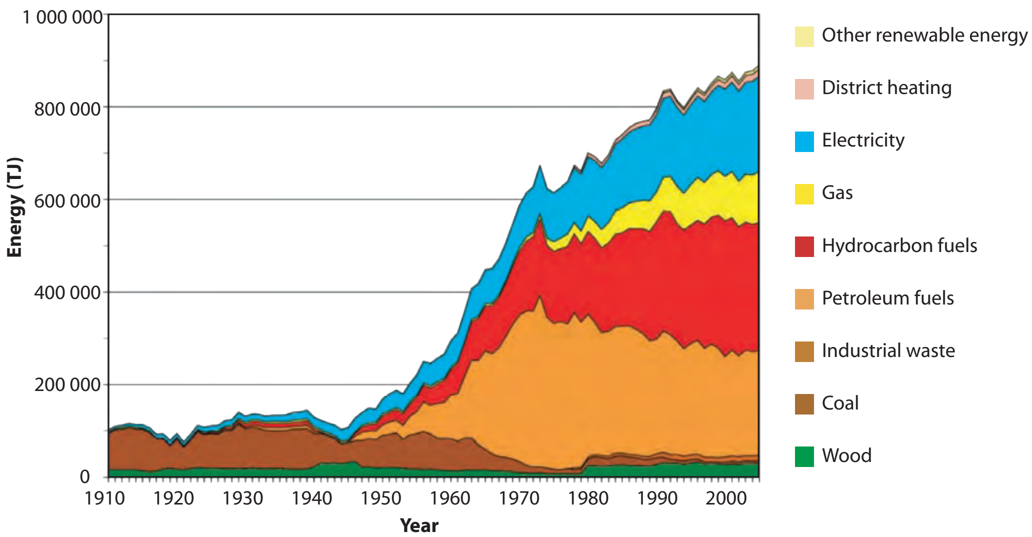

Figure 1: Energy consumption in Switzerland, split into different energy sources (1 TJ ≅ 0.3 GWh).
(Source: SFOE Overall energy statistics 2005)

in the demand from combustibles to electricity. The increase in air conditioning will be particularly pronounced in the service sector.

Electricity supply will be affected by climate change due to the negative impact on hydropower and nuclear energy. Hydropower production may have decreased by about 5–10% by 2050 because of the smaller runoff. With increasing water temperatures, nuclear energy plants will obtain less cooling capacity from rivers. In summer 2003, the lack of cooling capacity resulted in a reduction in annual production of 4%. Heat waves like in summer 2003 will increase between now and 2050.

The prospects for new renewable energy will increase as a result of climate change. On the one hand, the demand for CO_2-neutral energy will increase due to climate change and climate policy, and on the other, the competitiveness of renewable energy will increase due to the rising prices of conventional energy. As measured by today's consumption, the contribution of new renewable energy to the Swiss electricity supply will increase to more than 10% (5500 GWh/a)[1] by 2050. Wind energy will contribute to this. By expanding all wind farm locations to the maximum, the total potential of 1150 GWh/a could be tapped by 2050. Individual plants have an additional potential of 2850 GWh/a. With an increase in mean wind speed due to climate change, an increase in mean wind power production can be expected. In the case of extreme events, production failures can occur at individual wind farm locations.

Wood energy will also profit from the improved competitiveness of new renewable energy. Energy wood potential will allow at least a doubling of today's use in the future, to more than 5 million m^3. In consideration of the long-term forestry trends and the developments in the timber industry, the potential could even treble. However, competition in the use of wood will increase due to the use of other materials. Forest areas will expand as a result of climate change and the potential for wood energy will continue to grow. At the same time, the acceptance of wood energy will increase, provided that progress is made in the reduction of particulate matter emissions.

Altogether, higher energy prices will slow down the increase in energy consumption. Consideration of energy efficiency will bring about a shift towards electricity. The demand for CO_2-neutral energy (new renewable energy and nuclear energy) will increase. Generally, climate change will lead to an increase in uncertainty, which is why systems with short pay-back periods will be preferred.

The risk of service interruptions will also increase in the energy sector due to climate change. Examples of this include the flood of August 2005, which caused interruptions in run-of-river power stations, and the high water temperatures in summer 2003, which led to reduced energy production in nuclear power plants. Insurance solutions for property damage and production losses will gain in importance.

Measures

The emerging supply gap must be reduced as much as possible. In order to achieve this, the energy-saving potential must be fully exploited, and renewable energy, as well as technologies to promote energy efficiency, must be more strongly promoted. The electricity-saving potential by 2035 obviously depends on how much is spent on avoidance costs; the accumulated potential of up to costs of 40 Rp./kWh has been estimated to 10,000–15,000 GWh. The theoretical reduction potential in primary energy consumption by 2050 amounts to a total of 60%, whereas "Energy perspectives 2035" by the Swiss Federal Office of Energy[2] and "Road map" by the Swiss Academy of Engineering Sciences (SATW)[3] suggest a technical saving potential of 20–25%.

Future electricity production should remain CO_2-free. In order to avoid any additional net emissions by a possible new fossil power plant, further measures would have to be taken (combination of widespread use of heat pumps and savings in the heating energy sector, biological sinks, carbon capture and storage, emissions trading).

Diversification and redundancy are effective measures against the impacts of climate change on the energy sector. A broadly based portfolio of conventional and renewable energy protects against the supply shortfalls of a single energy source. Likewise, a network of several regional, medium-sized biomass power plants, for

instance, is less sensitive to disturbances than one single large plant. In distribution networks, redundancy must be strictly considered, that is, the provision of at least two independent connections between every two nodes.
While the emergency plans of the Federal Office for National Economic Supply are aimed at short-term shortages, they cannot offset long-term trends. It is therefore important to consider adaptation measures on the demand side as well. In addition to technical measures (e.g. load rejection during peak electricity consumption), consumer behaviour is also important. Consumers can adapt the acquisition of energy services that are not related to the production process to the conditions of a changed climate.

Links to other topics

Water management
Water levels of reservoirs and rivers; competition in water use, amongst others with agriculture (irrigation demand in summer)

Insurances
Losses due to and insurance of production losses

Land ecosystem
Expansion of forest areas, increase in inferior energy woods

2. Energy consumption

As a result of climate change, less heating energy will be used in winter and more cooling energy used in summer. Fuel consumption will thereby decrease and electricity consumption increase.

Current situation

In "Energy perspectives 2035/2050" by the Swiss Federal Office of Energy (SFOE), two energy scenarios[4,5] are compared in order to study the effects of climate change on energy consumption in Switzerland. In the reference scenario, climate change is not taken into account. In the "warmer climate" scenario, a temperature increase of 2 °C in the summer months June to August and 1 °C in the remaining months, compared to the period 1984–2002, is assumed by 2030. Radiation will increase by 5%.
With climate change, the meteorological statistical data that are important for the calculation of heating and cooling demand will also change. As a result of warming, the number of heating degree days (see box) in the heating period will decrease by about 11% by 2030, and by 15% by 2050, compared to the mean value for the period 1984–2004 (fig. 2).
Conversely, cooling degree days (see box) will have increased in the summer months by about 100% by 2035 according to "Energy perspectives". A temperature increase of about 2.5 °C by 2050, as the climate scenario in this report suggests, will mean an increase of about 150% in the number of cooling degree days (fig. 3).

Heating degree days:
Difference between the preferred mean room temperature (20 °C) and the mean outside temperature, totalled for all calendar days with $T < 12$ °C.

Cooling degree days:
Difference between the mean outside daytime temperature and the reference temperature (18.3 °C), totalled for all calendar days with $T > 18.3$ °C.

Service sector

The demand for heating energy by the service sector[4] will decrease slightly in the future even without global warming, due to higher energy efficiency and better heat insulation. By 2035, the demand will have decreased from 22,200 GWh/year to 20,800 GWh/year, in spite of economic growth. After 2035, the increase in energy efficiency and in heated area should roughly compensate each other, so that by 2050

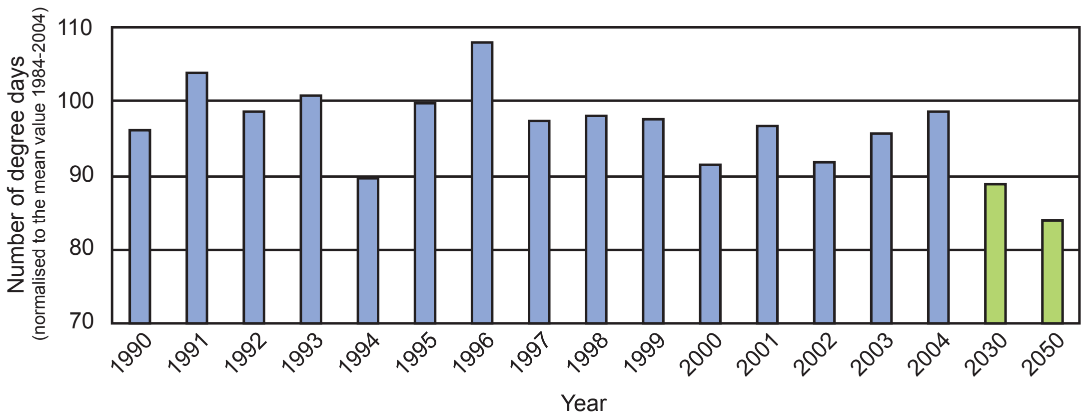

Figure 2: Annual heating degree days in the years 1990–2004, normalised to the mean value of the period 1984–2004. For the years 2030 and 2050, the expected values from the "warmer climate" scenario from "Energy perspectives 2035/2050" by the Swiss Federal Office of Energy SFOE are represented.[4]

the heating demand will still be around 20,800 GWh/year.

Due to warmer winters, the heating demand will have decreased by a further 13% to about 18,000 GWh/year by 2035. By the year 2050, heating demand will be about 18% below the reference scenario (just above 16,700 GWh/year).

Even without climate change, the electricity demand for room cooling will increase from about 1000 GWh/year in the year 2000 to about 1500 GWh/year in 2035, due to the increase in fully and partly air-conditioned areas. The proportion of air conditioning in the electricity demand thereby rises from 6% (2005) to 7% (2035).

Due to climate change, the specific electricity consumption for room cooling, as well as the demand for room cooling will further increase. The increase in cooling degree days means that the specific electricity consumption for room cooling will increase by about 46%. With regard to the demand for room cooling, it is assumed that by 2035 about 50% of today's non-air-conditioned areas will be partly air conditioned, and about 50% of today's partly air-conditioned areas will be fully air conditioned. Altogether, the service sector's electricity demand for air conditioning by 2035 will have increased to about 3200 GWh/year and lie about 115% above the reference scenario.

By 2050, the number of cooling degree days will have increased further. The specific electricity consumption for room cooling will have thereby

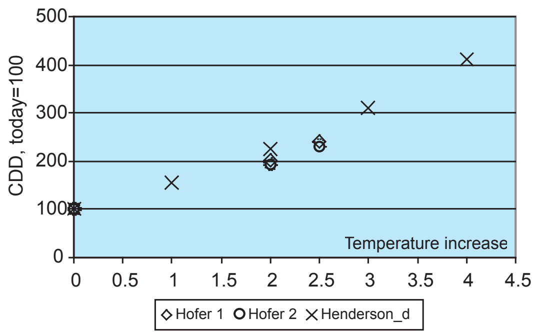

Figure 3: Change in cooling degree days (CDD) with a temperature increase of 1–4 °C in the summer months June to August (100=mean temperature in Switzerland today). Depending on the calculation method, the authors obtained slightly different values.[4]

increased by about 70% in comparison to the reference scenario. However, the proportion of air-conditioned areas will also have increased further, so that the electricity demand for air conditioning with building stock the same as in the reference scenario could be 170–200%, or 2800 GWh/year, above the reference scenario.

Private households

Excluding the impact of global warming, the demand for heating energy will decrease in private households from 55,000 GWh/year in 2000 to about 48,000 GWh/year in 2035, due to improved energy efficiency and heat insulation. For hot water consumption, the decrease is 1–2%. Including the impact of global warming,

the demand for room heating will decrease by a further 10% and amount to 44,000 GWh/year by 2035. By 2050, heating demand will have decreased by an additional 10% compared to the reference scenario.
As a result of global warming, an increase in electricity consumption for air conditioning in residential buildings in summer is to be expected. Marginal additional consumption is also expected for cooling and freezing appliances.
For Switzerland, there is currently no solid data available regarding air conditioning of residential buildings. The results for other countries can only be applied to Switzerland to a limited extent, since for most regions, construction methods, heating and cooling techniques, attitudes and behaviour differ significantly from Swiss circumstances. In Switzerland, it is assumed that the specific cooling demand will be smaller for the residential sector than for the service sector (different internal loads, day/night consumption rhythms etc.) and that air conditioning in the residential sector will be largely decentralised using compact or split systems (with air or water cooling). Altogether, an increase in electricity consumption by about 10% compared to the reference scenario is expected by 2050 (fig. 4).
The additional electricity demand expected for air conditioning can be restricted if innovative concepts, such as free-cooling (dissipation of heat into the air during the night), geocooling (dissipation of heat into the ground using the same geothermal probes that deliver ambient warmth for the heat pumps in winter) or solar cooling are increasingly introduced.

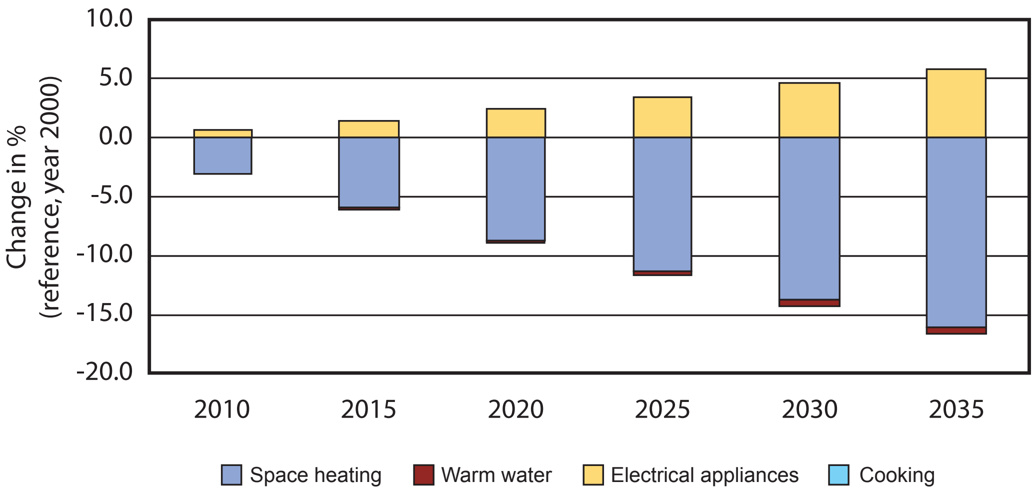

Figure 4: Changes in energy consumption in private households according to type of use, compared to the reference scenario (today: 75,000 GWh)[5].

3. Established electricity production

In the near future, domestic electricity demand will no longer be able to be met by domestic energy production. Due to climate change, there will be production losses for hydropower. Against the background of climate change, the supply gap must be closed through the stronger promotion of renewable energy and the use of technology to enhance energy efficiency, as well as by new CO_2-free production capacities.

Current situation

Electricity production in Switzerland is largely CO_2-free thanks to the two mainstays, hydropower and nuclear power. Municipal waste incinerators and industrial combined heat and power plants account for the largest proportion of conventional thermal facilities.

The net capacity of the five nuclear power plants is 3220 MW. They produce about 25,000 GWh electricity per year, which corresponds to around 40% of the Swiss electricity demand. In 2020, the first nuclear power plants will reach the end of their operating time. Swiss production capacities will decline strongly thereafter. At the same time, import contracts for electric power with Electricité de France (EDF) will gradually run out.

Electricity consumption is likely to further increase in the future. In the past, electricity consumption increased by 1.8% per year with a growth of the GDP by 1%. SFOE estimates that by 2035, growth will be 22.3% slower compared with 2003 if today's policies continue. The introduction of a CO_2 tax would slightly increase growth (+23.2%), since the expected increase in energy efficiency will be accompanied by an increase in electricity consumption. If the linear trend continues, the electricity demand will be about 33% higher by 2050 compared to 2003. The Axpo[6] suggests slightly higher values in its scenarios (fig. 5). The spread of the different scenarios shows the uncertainties regarding future electricity demand.

From 2020 to 2030, domestic electricity demand will not be able to be covered by domestic power production and existing import contracts. After 2012, the import of electric power will regularly exceed the export of electric power in the winter half-year.

Climate change

Climate change is an important influencing factor in power production. Hydropower strongly depends on water supply (precipitation and meltwater), which is directly affected by climate change. Nuclear energy depends on sufficient amounts of cooling water.

The established energy sources, hydropower and nuclear energy, will be influenced by future climate change as follows:.

- In the short term, more water will be available for hydropower due to melting glaciers, and more electricity will therefore be produced in summer. In the long term, water supply and production will decrease in summer. The reduction in runoff is due to decreasing precipitation and increased evaporation.[7] The reduced runoff could result in a decrease in hydropower production of 7% on average by 2050.[8] In addition, an increase in floods is expected in the midlands due to climate change. Part of this water cannot be used for power production. The loss in electricity production is therefore larger but not quantifiable.
- Due to higher water temperatures, water-cooled nuclear power plants will obtain less cooling capacity from rivers, and production will decrease. In summer 2003, the performance of nuclear power plants had to be curbed by 25% for two months. This reduced the electricity production for the year by 4%. Water temperatures in rivers will continue to increase up to 2050 (see Water management chapter). As a result, there will be production restrictions.
- The pressure to reduce the use of fossil energy will increase with climate change. Being CO_2-free, hydropower, nuclear power and new renewable energy do not contribute to climate change and will not be burdened by possible steering taxes.

Measures

Electricity production should remain CO_2-free. Against the background of climate change, important measures to close the supply gap are as follows:

- Intensified promotion of renewable energy and technologies to enhance energy effi-

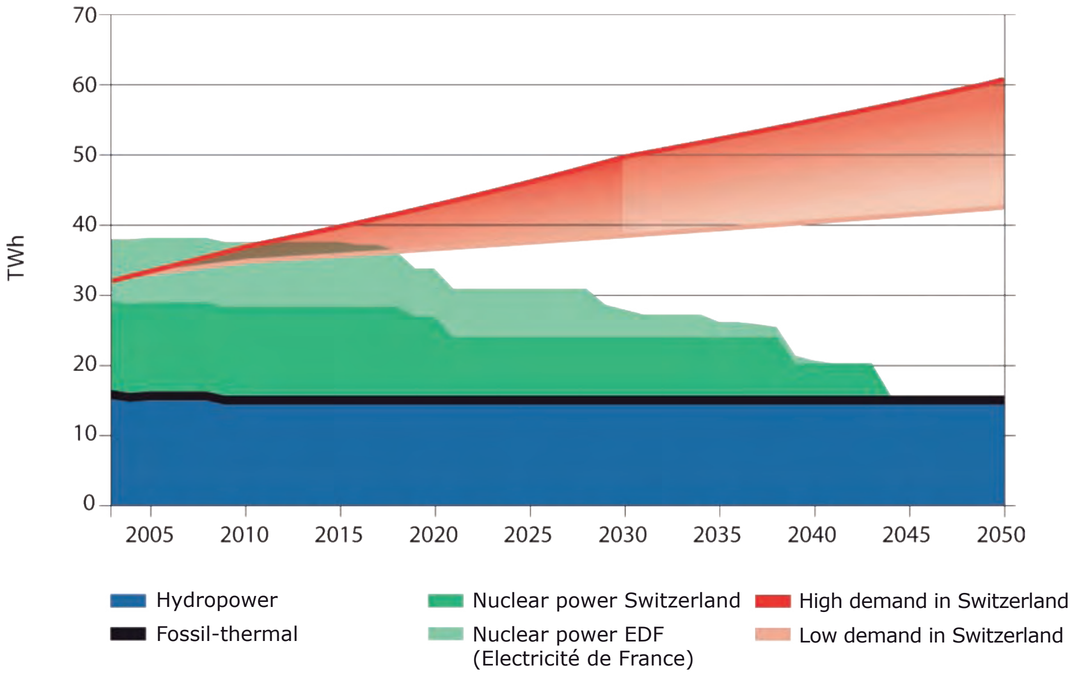

Figure 5: Production capacities and electricity consumption in Switzerland in the winter half-year. According to the projection, domestic power production and existing import contracts will be unable to cover domestic electricity consumption after 2012 (high power demand scenario) or 2019 (low power demand scenario).[6] (1 TWh = 1000 GWh)

ciency, as well as tapping the full potential of energy savings. In addition to research and development, pilot plants are necessary in order to demonstrate the feasibility of such technologies and to gain experience. Though by enhancing energy efficiency, electricity demand will tend to increase.

- Supply of new, CO_2-free production capacities. To close the supply gap, a gas-fired power plant, as a temporary solution, and a new nuclear power plant, as a long-term solution, were recently proposed. In order to avoid any additional net emissions this caused, further measures would have to be taken (biological sinks, carbon capture and storage (CCS), emissions trading). Carbon capture and storage technology will only be available after 2030 or later. Storage is particularly critical, since it is required over long periods of time – similar to the storage of nuclear waste – and therefore is a political issue. This is true for storage in Switzerland as well as abroad.
- Switzerland will decide in a democratic political process what form its future energy supply will take. A comprehensive and objective compilation of all the scientific facts (natural, social, economic) is required in order to make an educated decision. Decisions regarding future electricity production will affect the degree of international dependency of the Swiss energy supply on gas, electricity and other imports. Therefore, tapping the potential of domestic renewable energy as much as possible is to be aimed for.

4. New renewable energy

The direct impacts of climate change on power production from renewable energy are classified as being between neutral and slightly positive. While the growth of biomass will tend to be favoured and solar radiation will increase slightly, extreme events will have a potentially negative impact. However, more important than these direct influences is the fact that increasing energy prices and climate protection strategies will improve the general conditions for the promotion and introduction of renewable energy.

As measured by today's consumption, the contribution of new renewable energy (NRE) to the electricity supply of Switzerland could increase from 3% today to 10% (5500 GWh/year) by 2035.[9] By 2050, a further increase will be possible. Basically, this 10% comprises a large part of the potential for small-scale hydropower and wind power, substantial contributions from biomass and geothermy, as well as a relatively small contribution from photovoltaics. The potential of NRE will be limited by the higher production costs.

Climate change increases the prospects for NRE. The increasing demand for energy and the measures (agreed on and anticipated) to limit greenhouse gas emissions increase the demand for CO_2-neutral energy. At the same time, subsidy needs decrease with higher energy prices. If the subsidies remain constant, faster market penetration is expected.

The production of NRE will be influenced by environmental factors on different time scales. The efficiency of renewable energy forms depends on weather and climate, among other factors, and is affected by climate variability and extreme events. The climate scenario of this study shows a change in mean values and does not comment on the changes in variability. There is evidence for an increase in temperature variability in summer and a slight decrease in winter.

Variations in climate could also affect medium-term planning for NRE production. A possible approach could be to model the entire chain, from the climatic boundary conditions as input data to energy production.

Wind energy

Potential

Switzerland today has about 5.4 MW[1] of wind power installed and produces around 5.4 GWh/year of its electricity from wind. This represents barely 0.01% of the entire domestic electricity production in the year 2003. Even with the 15 GWh electricity from photovoltaics, the contribution of the new renewable energy has up to now still been low.

The potential for wind energy is limited in Switzerland. An expansion of wind power to 600 GWh/year will be possible by 2035. By 2050, a total potential of 1150 GWh/year could be tapped through maximum expansion of all the wind farm locations. If measured by electricity production in 2003, the proportion of wind power would amount to 1.8%. The potential of individual installations amounts to another 2850 GWh/year.[9]

The general technical possibilities of integrating wind energy into the electricity grid include the provision of backup capacities, disconnection of superfluous wind power, and storage. In Switzerland, wind power can be integrated into the electricity grid without difficulty, even at its full potential; maximum expansion of wind power would still not influence the stability of the electricity net. Short-term fluctuations in wind power production could easily be absorbed by hydropower. New storage technologies such as hydrogen will even further improve the compensation possibilities in the future.

Climate change

The impact of climate change on the mean wind speed in Switzerland is not clear. Possibly there will be a change in the mean wind speed and an increase in extreme events. Both would have an impact on wind power production. Mean wind speed directly affects electric power output, with an increase in mean wind speed leading to an increase in mean wind power production. In the case of extreme events, production interruptions may occur at individual locations. However, a breakdown of all the wind power plants is statistically unlikely..

Measures

For Switzerland, the impacts of climate change on the use of wind power are of a rather indirect nature. The challenge is in fact to enhance the expansion of wind power in neighbouring countries. The following measures will contribute to the optimal integration of wind energy:

- Improved wind forecasts and at the same time, a reduction in schedule reporting time, with which network operators are notified about the expected electricity production in advance for planning. The shorter the schedule reporting time, the more accurate the predictions of the expected electricity production from wind power.
- Improved planning base for consideration of environmental concerns, in particular those of nature conservation and landscape protection.
- Grid networks – the larger the net, the smaller the demand for backup power, i.e. conventional production capacity that needs to be available in order to compensate for reductions in wind power production as a result of unfavourable wind conditions.
- Transparent, cross-linked and well functioning markets can considerably reduce the costs of integrating wind power. In this respect, a liberalisation of the electricity market may be helpful, if it enables feed as well as load compensation over as large a catchment area as possible.

Biomass: Wood energy

Potential

The total ecological biomass potential was 34,000 GWh in 2001.[9] Wood, groves, hedges and orchards contributed the greatest proportion, with 12,800 GWh (fig. 6). The ecological biomass potential allows for a distinct increase in electricity production. Firstly, the amount of biomass products suitable for energy production will likely increased. Secondly, the development in conversion technologies will be able to improve the conversion efficiency to electricity by a factor of 2–3.

In 2004, 2.8 million m^3 of wood was used in Switzerland, primarily for heating. In particular, there has been a strong increase in the use of automatic wood heaters in the past decade. The energy wood potential allows for at least a doubling of today's use to more than 5 million m^3 in the future, provided that progress is made in the reduction of particulate matter emissions.[10] The potential could treble as a result of long-term trends in forestry (tree species appropriate to the location, graduated ecological forestry, extensive forest management, regional mechanical harvesting), as well as of developments in the timber industry (increase in sawing capacity). However, competition in the use of wood will increase because of other utilisers (building materials). Supply and demand will determine the price and, therefore, the use of wood.

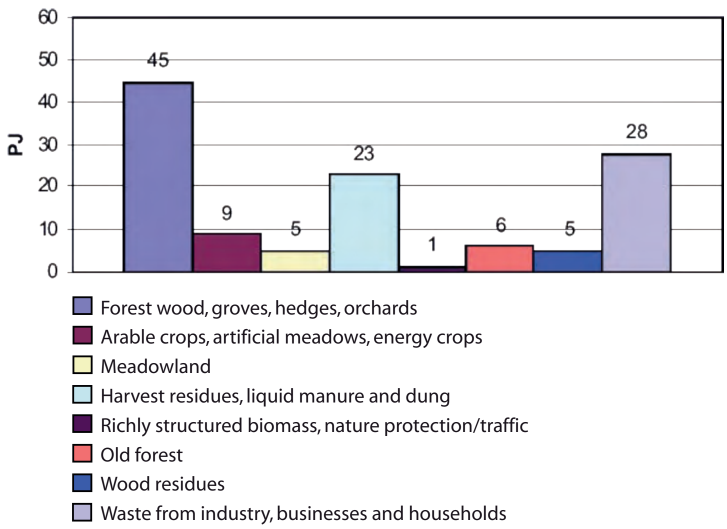

Figure 6: Ecological biomass potential in the year 2001, split into different sources.[9]
(1 PJ = 278 GWh)

Impact of climate change

Climate change will generally have a positive impact on the use of wood energy. Firstly, forest areas will expand (see Land ecosystems chapter) and the potential for wood energy will grow. Secondly, the acceptance of renewable energy and of measures to promote energy efficiency will increase in response to climate change and as a result of climate policy. In politics, federal administration and the economy, willingness to introduce measures to promote the use of wood energy is increasing.

Climate change and the increased use of wood energy will affect forests. The forest landscape will change. Altogether, there will not be more wood in the forests but the proportion of energy wood and wood of inferior quality will increase. A possible increase in extreme events, such as the Lothar storm in winter, December 1999, would cause large biomass losses and correspondingly, forced utilisation.

Short-term climate forecasts

Out of the ordinary climate conditions such as the European heat wave and drought period in summer 2003 but also the cold winters in the 1960s, already affect energy production and energy consumption in today's climate. For some time now, there have been attempts to predict these climatic fluctuations by means of numerical climate models. However, like the weather, the climate system has chaotic elements, and predictions are highly sensitive to small uncertainties in the initial conditions. Recently developed probability forecasting now considers this sensitivity by calculating not one but many projections with slightly different initial conditions. From this ensemble forecast, it is possible, for instance, to calculate the probability of a cold January or a hot summer (fig. 7). Such short-term climate predictions must be interpreted and used with caution at the moment; their quality varies depending on the region, and in particular, on the required forecasting period. However, probability forecasting enables prediction of expected weather for more than one week ahead and thereby offers interesting planning possibilities for professional use, such as in energy management.[11,12]

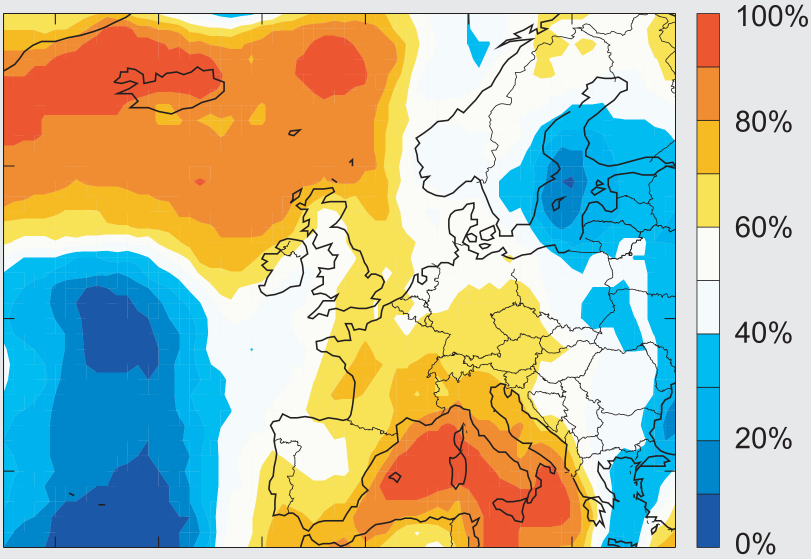

Figure 7: Probability of temperatures above the climatic mean for summer 2003: Prediction made in 1 May 2003.

5. Economic aspects

It is widely agreed that energy prices will rise due to the scarcity of oil resources and climate change. This trend will reduce the energy intensity of the gross national product and weaken the increase in global energy consumption. Adequate adaptation measures in the energy sector will not only limit the damage costs but also the costs for the energy system itself, so that in the best case there may be real synergies between adaptation and mitigation.

Development of energy prices

Energy prices will not go down again to the low level of the period 1985–2000 and could further increase in the medium- to long-term due to political shifts. The following developments will contribute to this:

- The global demand for energy will strongly increase. The International Energy Agency (IEA) expects an increase of 50% in the demand by 2030.[13] 60% of the increase would have to be covered by oil and gas.
- In Switzerland, the demand for energy services will also continue to increase (see section 3). At the same time, there will be a shift from heating energy (combustibles) in winter towards cooling energy (electricity) in summer as a result of climate change (see section 2). Depending on the scenario, the increased demand can be covered with less final energy, while the proportion of electricity increases with efficiency strategies.
- Due to climate change, hydropower and nuclear energy production in Switzerland will decrease in summer if fixed costs remain constant.
- Climate change increases the variability of the hydrological cycle. More frequent extreme events will result in more interruptions and damage. Examples of this are the flood in August 2005, which led to interruptions for river power stations, or the high water temperatures in summer 2003, which resulted in reduced energy production by nuclear power plants.

An important influencing factor in the development of energy prices is the question of whether the external costs of CO_2 emissions can be sustainably internalised (for example by certificates, steering taxes, support measures). There is large uncertainty about the long-term development of CO_2 legislation. For one thing, there is uncertainty about the prices for oil, gas and electricity. In the case of high energy prices, it can be assumed that the politically determined CO_2 costs will decrease, since high energy prices would further increase the costs of fossil energy. For another thing, the CO_2 costs depend strongly on the question of whether all nations worldwide will take part in climate protection agreements in the context of the Kyoto protocol. In the event that important nations continue to opt out, there will be a geographical shift in energy production. Altogether, higher energy prices will slow down energy consumption. Due to considerations of energy efficiency, there will be a shift towards electricity. The attractiveness of CO_2-neutral energy (new renewable energy and nuclear energy) will increase.

Generally, climate change will lead to an increase in uncertainty, which is why systems with short pay-back periods will be preferred.

Economic modelling of adaptation and mitigation measures

As a result of climate change, the proportion of the gross national product that is available for consumption will decrease for the following reasons:

- The damages caused by climate change will have to be resolved by the national economy.
- Preventive actions against the damages will have to be taken and financed.
- Climate protection measures to reduce greenhouse gas emissions will require additional expenditures.

From an economic perspective, the first two items are considered to be adaptation costs, the third package of measures comprises the mitigation costs. In order to arrive at an optimal long-term strategy, future costs and benefits of climate change will have to be estimated and compared. This is achieved by discounting future consumption and future deadweight losses using an interest rate of typically 1.5 to 5%, depending on the time horizon. Such a sober economic approach has the advantage of suggesting the optimal behaviour of the global community of nations: Both doing nothing and taking exaggerated measures are more expensive than a tailor-made climate protection policy that maximises long-term welfare.

From such analyses, it can be deduced that a specially tailored climate policy will pay off economically. Deadweight losses will be minimised and remain within the magnitude of less than 2% of the reference development without climate change. Finally, the proportion of energy costs in the gross national product will decrease slightly as a result of climate protection measures.

Literature and notes

1 GWh/a = gigawatt hours per annum. 1 GWh = 1 billion kWh. 1 Petajoule (PJ) = 278 GWh. MW = megawatt (power)

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Buildings and Infrastructure

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1. Introduction

Background

Population development, employment trends and mobility behaviour are important factors for the building and infrastructure sector. In the last decades, urbanisation has increased significantly in the midlands. Some agglomerations are not only growing but are joining with others. Mobility (kilometres travelled) has also considerably increased. The spatial separation of the home and working environment not only results in a steady increase in traffic but also increases the need for a functioning infrastructure. Housing space is extending to zones at the edge of or beyond the previous settlement areas, which are riskier with regard to extreme weather events. All together, these developments have resulted in a complex system that is becoming increasingly vulnerable. At the same time, costs rise if system elements collapse or fail. In order to reduce or prevent damage, the risks of climate change need to be estimated and considered early enough. Due to the long lifetime of buildings and infrastructure, it is important to adapt decisions regarding architecture, land use planning, building concepts and building services engineering to current and future climatic changes at an early stage. Firstly, additional costs for later measures may be thereby avoided. Secondly, adapted construction methods will reduce potential damage due to weather and climate. Thirdly, security and comfort of the living and working environment, as well as operational reliability of transportation will be improved.

The settlement elements examined in this chapter include the buildings of the living and working environment, road and rail networks, and urban water management (fig. 1, blue background). The remaining aspects of water, such as natural water bodies, water as a natural hazard, water supply and demand, and water usage are covered in the Water Management chapter. The energy sector is discussed in a separate chapter. As an overarching concept, settlement as a whole is also covered in the Buildings and infrastructure chapter, although only urban settlements are discussed.

The following aspects of climate change are of particular importance with regard to the buildings and infrastructure sector:

- Temperature rise / increase in heat waves
- Changes in water balance
- Increase in heavy winter precipitation
- Increase in winter storms
- Increase in thunderstorms with hail, heavy precipitation and wind gusts

In considering the effects on settlement elements and settlements as a whole, the emphasis is on two aspects: (1) quality of life and work, (2) stability and conservation of value of buildings and infrastructure.

Overview

Settlement elements: buildings

Indoor environment

Newer buildings normally have good heat insulation, which reduces the heating demand during the cold season. In summer, the heat penetrates indoors slightly more slowly but is also released outwards more poorly. Cooling can become necessary due to sunlight, and additional heat produced by machines, lighting and people, in

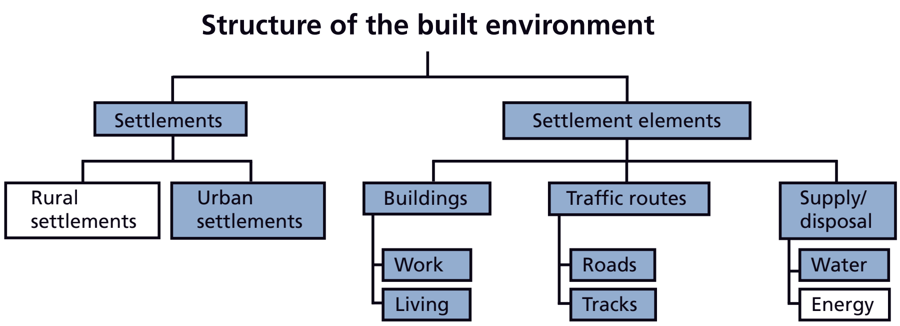

Figure 1: Overview of the areas dealt with in the Building and infrastructure chapter (blue background). The structure of the built environment is discussed as a synthesis aspect due to its strong interconnectedness with other topics (see Urban Switzerland chapter). Rural settlements are not specifically addressed, the energy sector is dealt with in a separate chapter.

particular for offices and other service company buildings, and industrial plants. With climate change, the cooling period will get longer and the probability of heat waves will increase. Anticipatory measures, such as the use of energy-efficient devices, automatically controlled lighting and sun screens, good (window) ventilation and highly efficient building cooling systems can contribute to improved room climate.

Building shells and entire buildings
For building shells, an early adaptation of building norms is particularly important. These norms are currently based on mean values of past observation periods but urgently need to be adjusted to the future climate.
The risk for entire buildings primarily results from the expected increase in extreme weather events. Such events may result in great financial damage, which, however, cannot entirely be attributed to climate change. Other important factors are the increasing concentration of assets, the growing risk vulnerability and the extension of residential buildings into areas that used to be considered too risky. Town planning therefore also has an important role to play. In areas at risk, zone planning and protective measures need to complement one another optimally in order to minimise the costs.

Rail and road network
With regard to the effects of climate change on the rail and road network, the largest problems are expected due to changes in the terrain, in particular as a result of the increase in heavy precipitation. Mudflows, avalanches and landslides can cause heavy damage to infrastructure. It is important to consider in this context the fact that natural hazards increase over the years independent of climatic changes, purely due to increasingly valuable infrastructure. In many cases, solution strategies are at hand and need to be adequately applied on a broader scale. Especially where road traffic is concerned, judging the necessity of measures also requires comparison with other risks, in particular that of traffic accidents.

Urban water management
The impact of climate change on urban water management is only partly assessable. Water supply will very likely be secure in spite of a changing demand (e.g. increased demand in summer) through optimised water management. With sewage disposal, rising temperatures, dry spells but also heavy precipitation may require adaptations in the operation of sewage plants.

Urban settlements
The temperature increase, as well as the increased frequency of heat waves or hot spells will particularly increase the heat load. In view of the health implications, consideration of this fact is imperative in spatial planning. Adequate measures to reduce the heat load can, as an additional positive effect, improve air quality.

Links to other topics
Energy
The savings in heating energy will be partly compensated by an increased demand for electricity for air conditioning.

Health
Particularly in urban areas, the increased heat load can cause health problems.

Agriculture
The increased water demand for agriculture and households can cause conflicts.

Tourism
Tourism strongly depends on a reliably functioning infrastructure.

Insurance
Natural hazards may result in increasing damages. Adaptation strategies to cope with climate change can reduce risk vulnerability (e.g. shatter-proof roof glazing) or increase it (e.g. sun protection).

2. Buildings

Room climate

With global warming, the demand for air conditioning will increase. Appropriate construction methods for new buildings and adequate renovation of existing buildings make it possible to cool buildings energy-efficiently and thereby minimise the costs.

Today, new and renovated residential and office buildings have good or very good insulation, which in winter reduces the heat requirement for room heating. At the same time, the improved insulation of the building shells reduces the outward transport of the heat that enters the building or is produced within the building in summer. In the case of large heat sources within the building and large amounts of incoming sunlight, this results in heat accumulation and therefore a cooling demand, in particular for utility buildings (see Energy chapter, section 2). Global warming will extend the annual cooling period and during hot spells, the room temperature may become a burden. As a result of this but also due to rising comfort demands, the importance of air conditioning will increase.

Office and other utility buildings

Thermal load and labour productivity

In office buildings, high outdoor temperatures, interior heat loads and sunlight often result in particularly unpleasant conditions. Many buildings have large glass panels through which light and solar energy can enter. In the room and within the glazing, the light is partly transformed into heat. Electronic equipment such as computers, copiers and printers produce additional heat. A high concentration of people in office buildings and lighting likewise add to the heat load. Good heat insulation, which is indispensable for low heating demand and for reasons of comfort even in a warmer climate, makes it almost impossible for the heat to escape through the windows or the rest of the building shell. On sunny and warm days, this results in high room temperatures, which are not only unpleasant but also reduce labour productivity. Studies have shown that for office work, labour productivity in summer decreases at temperatures above 26 °C.[1,2,3] In the heat-wave summer of 2003, the temperature in an average, non-air conditioned office space reached more than 26 °C (fig. 2) on 22 days within a time period of four weeks, despite the use of night cooling. In an average summer, this is the case for seven days. For office buildings without night cooling, which is still the norm today, the comfort threshold will be exceeded much more frequently.[4] Consequently, the cooling demand is not limited to extraordinary heat periods but also arises in the course of an average summer.

Adaptation of existing buildings

In existing buildings, the problem of heat load can be resolved by good sun protection, energy-efficient and automatically controlled (e.g. daylight- and movement-based) devices and lighting, the possibility of opening the windows, and the installation of cooling systems. Through technical optimisation and by making use of synergy effects with the heating supply, investment and running costs can be minimised. In new buildings, appropriate construction methods can make the installation of air-conditioners superfluous. So-called free cooling systems or highly efficient air conditioners use a fraction of the energy of today's standard of air conditioners and cooling systems.[6] Such systems use outdoor coolness as much as possible (e.g. low outdoor temperatures during the nighttime, evaporation, heat pump ground probes) to cool ceilings, floors and walls, which can again absorb warmth from the ambient air the next day. Architectural measures can make a considerable contribution, for instance sun protection (although an increase in the danger of hail and storms must be taken into consideration, in particular for high buildings; see Building shells section), room depth, window size and orientation, and architectural landscape elements, such as trees, lawns and water features.

Efficiency and energy demand

Provided that the critical points mentioned are taken into consideration in future building, overall the savings in heating energy are expected to be larger than the additional energy

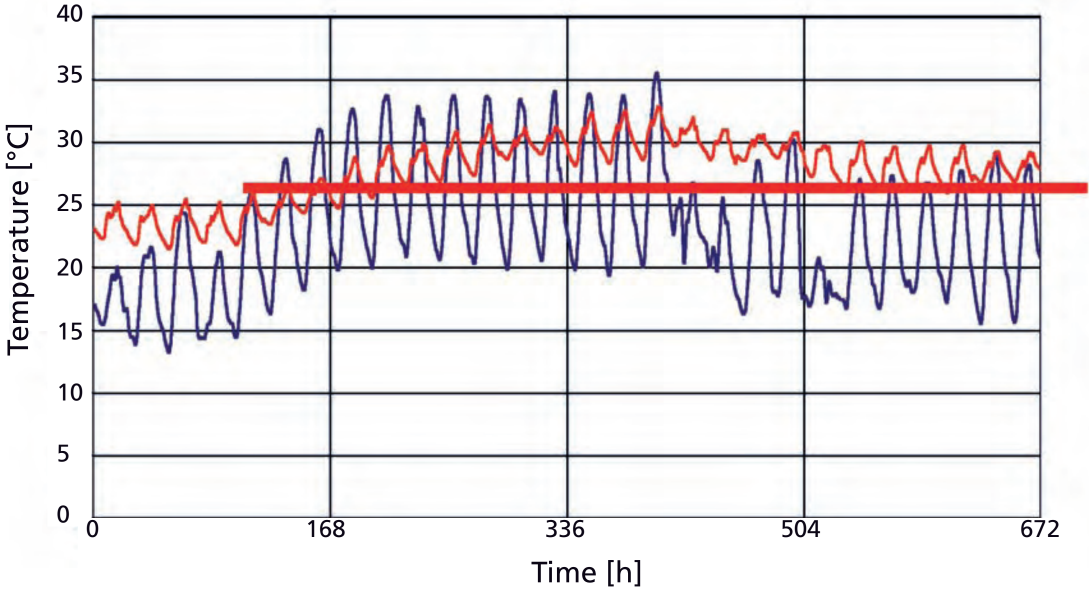

Figure 2: Calculated temperature profile for four weeks during the heat-wave summer of 2003, location MeteoSwiss Zurich. Outdoor (blue) and indoor (red) temperature in an office building with a large proportion of glass (80%), good sun protection (g=0.10), moderate internal loads (15W/m^2), comfort cooling during the day and intensive night cooling (nL=0.3h^{-1}). The comfort threshold of 26 °C (red bar) is exceeded on several days. Above this threshold, workplace productivity decreases rapidly. (Source: Frank 2006)[5]

demand for cooling. However, this change means a shift in the energy demand from fuels to electricity (see Energy chapter, section 2). There are economic and resource policy reasons for cooling buildings as efficiently as possible (see Energy chapter, section 5), in particular also in view of the enormous energy savings in comparison to inefficient cooling measures. A particular challenge in this respect is the fact that efficient building cooling requires the careful coordination of different elements (e.g. insulation, ventilation, shading, windows). Such integrated conception and planning is still the exception today. On every level, it is primarily the investment costs rather than the life cycle costs that are minimised, which prevents the realisation of carefully coordinated systems. Therefore, an urgent need for action exists in energy policy at the legislative level in the sectors concerned, as well as for builders, and building owners, operators and users.

Adaptation costs

Additional costs must be expected for the adaptation of existing office buildings and other utility buildings, such as shopping centres, hospitals, homes and schools, where air conditioning, air conditioning refurbishment and improved sun protection will account for the largest proportion of the costs. According to a study on behalf of the Swiss Federal Office of Energy[7], protection against overheating alone will cause costs of 10 Swiss francs per square metre a year. Today, office space amounts to about 40 million m^2, altogether the heated and lit area of the service sector amounts to more than 150 million m^2. Cooling two thirds of this area would cost 1 billion Swiss francs per annum. However, the benefit gained by higher labour productivity and workplace attractiveness is estimated to be even higher, which is why cooling of buildings will become an important topic in the coming years.

Residential buildings

In residential buildings, adequate construction usually avoids the need for cooling devices, in particular because of the nighttime cooling through opening the windows. Good and possibly also automatically controlled sun protection reduces the external heat load. Adequate ventilation, e.g. by means of earth tubes, as well as window and nighttime cooling through appropriate ventilation flaps and vents, dissipates the heat. Both measures – reduction of the heat load and dissipation of existing heat – contribute to a comfortable indoor climate. The effect of nighttime cooling can be enhanced by using the indoor storage capacity, for instance by means of exposed concrete ceilings, carpet-free flooring and plasterboard-reinforced attics. The use of ground probes as a relatively energy-efficient cooling source is also worth mentioning.

Building shell

The expected increase in intensity and frequency of extreme weather events endangers damageable elements of the building shell. Today's construction standards, which are based on the mean climatic values of past observation periods, need to be adapted to the future climate.

The vulnerability of structural elements on the outside of buildings could possibly increase in the future. Firstly, the frequency and/or intensity of extreme weather events is expected to increase (e.g. heavy precipitation, winter storms) and secondly, the number of constructions easily susceptible to damage will likely increase. These can be shade devices for protection against the warming climate, insulation or devices for energy saving and generation (e.g. solar panels). The variety of materials used for roofs and facades has increased. With office and industrial buildings in particular, materials with inadequate hail resistance are often used. These are translucent synthetic materials, steel sheets and sun screens (fig. 3).

Up to now, the requirements for the security of structural elements on the outside of buildings have been based on the mean values of past climate observation periods. These requirements are codified in construction standards. Not only technical installations (e.g. masts and towers, long-span bridges, greenhouses) and buildings at extreme locations (e.g. in the high mountains, in the vicinity of rivers), but also ordinary buildings are affected by more severe weather impacts. The anchorage of light facades and roof coverings, shatter resistance of roof glazing, weatherability of shading equipment and solar panels need to be examined for existing buildings, and adjusted to the future climate for new buildings.

Figure 3: Hail damage in facade made of synthetic material, Wetzikon 2004.
(Source: Thomas Egli)

Extreme events and threats to entire buildings

The possible increase in floods, heavy precipitation, storms and hail events can endanger buildings and lead to great financial damage. The changing risks require the adaptation of building regulations.

Floods

When floods occur today, they usually cause great financial damage in the area of infrastructure. This cannot be attributed to climate change but to the concentration of assets, that is, the risk of damage increases with the continuous expansion of the road and railway networks and the building of bridges and houses. Furthermore, in comparison to the past, building activities have extended into areas that used to be considered too risky and were therefore avoided.

The question of whether floods will become more frequent with climate change cannot be answered conclusively by the scientific community (see Water management chapter, section 3). An increase in frequency seems probable, in particular in winter and the transitional seasons. The midlands, the foothills of the Alps and Ticino would presumably be primarily affected. In order to prevent an increase in the extent of flood damage with climate change, flood protection needs to be reassessed regularly. The flexible strategy that Switzerland currently pursues (see Water management chapter, section 3) aims primarily at preventing damage and not necessarily at avoiding floods.[8]

Storms

Buildings that are particularly exposed, such as aerial towers, are strained close to the stability limit by storms as intense as Lothar (December 1999). If the number of such storms increases, this will require the tightening of building regulations.

Heavy rain

The expected increase in heavy precipitation is to be considered in the dimensioning of property drainage. This affects ground floors and cellars of buildings that border on slopes and hollows. In city centres, the risk may also increase, since drainage is often dimensioned for less heavy precipitation.[9]

Hail

Between 1983 and 2003, the number of large hailstorm tracks (track length > 100 km) doubled in Switzerland.[10,11] The large hailstorm tracks cause hailstones of large diameter. They damage sensitive roof and facade materials, such as synthetics, steel sheets and external insulation. Shading equipment is generally very susceptible to the effects of hail.[9]

Figure 4: Snow pressure caused the collapse of a hall roof, Waldstatt 2006.
(Source: Thomas Egli)

Snow load

The expected increase in winter precipitation may cause static problems for roofs at elevations where precipitation falls as snow. Too high snow loads can result in extensive damage or, in the worst case, even the collapse of the roof. Halls with large spans of lighter building materials, such as wood or steel, are particularly at risk. In such cases, the snow load is large in comparison to the self-weight. Flat roofs are also at risk, in particular if the previously fallen snow has turned to ice due to bad insulation and the new snowfall further increases the load. In order to minimise the risk of roof collapse, the possible future increase in snow load must be considered in the planning of private and public buildings.

Avalanches

The risk of avalanches may change with global warming but it is unclear whether they will become more or less frequent. Independent of a change in the overall number of avalanches, their frequency may also change for certain regions. In any case, minimising the costs requires risk analysis and adequate measures (zone planning, protection measures).[8] The avalanche winter of 1999 showed the possible extent of damage due to snow masses.

Uncertainties/Open questions

To estimate the temperature and humidity behaviour of rooms, as well as their impact on comfort and productivity requires improved models. Furthermore, the question of thermal comfort should not be considered separately but should be integrated with microclimatic and energetic issues.

3. Transport networks

Rail network

The effects of climate change on the rail network can be attributed primarily to the possible increase in extreme weather events. Heavy precipitation events put line stability at risk, and storms and heat waves can cause damage to overhead contact wires and rails. Appropriate countermeasures prevent an exponential increase in loss amount.

Line stability and security

Already today, railway lines are regularly exposed to natural hazards, primarily due to extreme weather events such as long rain periods or strong snowfall. Thus, numerous railway stations were flooded in connection with the floods of August 2005 (fig. 5). Heavy precipitation may not only result in floods but can also cause landslides and mudflows. Build up of water and waterlogging within the vicinity of the tracks, as well as bank erosion and mudflows from drainage channels, are further possible outcomes.

Figure 5: August 2005 flood, Dornibach/SZ
(Source: SBB)

Precipitation

The threat to line stability will increase with the predicted increase in winter precipitation, which will increasingly fall as rain at lower elevations, and with the expected increase in heavy winter precipitation In particular, the stability of embankments and slopes will be increasingly called into question. Heavy precipitation may also cause the undermining of lines.

The future frequency of instabilities and drainage problems will not only depend on precipitation amounts and intensity. The soil water content and water storage capacity of soil and loose rock, as well as water from nearby drainage channels, will also be important factors. This particularly applies to summer, in which total rainfall tends to decrease but the rain increasingly falls on parched soil.

It seems probable that the instability of embankments and slopes will rise with increasing precipitation. Apart from railway lines in the vicinity of slopes, the possibility that railway stretches built on artificially cut-out slopes in the midlands and the foothills of the Alps will slide away should not be underestimated. There, heavy precipitation may also lead to water logging, instability and hence to landslides.

Above the snow line, larger winter precipitation amounts may result in an increase in the danger of avalanches or blocking of infrastructure (switch blocking, restricted visibility, snow piles on the lines). With regard to avalanches, the railways have a land register of the relevant avalanche tracks. Already today, critical areas are secured with protective galleries or are closely monitored during heavy snowfall. The safeguarding of further avalanche tracks could be realised relatively straightforwardly in the event that such a need arises.

Temperature

The consequences of the mean temperature increase and the presumably more frequently occurring heat waves on line stability and security will primarily be of an indirect nature. The effects may result from the melting permafrost as well as possibly from the changes in thaw and frost processes.

The heat-wave summer of 2003 showed the consequences of high temperatures on slope stability. In the course of that hot summer, a great number of rockfalls and rock avalanches were observed in the entire alpine region, in particular at higher elevations and on north facing slopes. This extraordinary rockfall frequency can be interpreted as a sign that the destabilisation due to extreme heat occurs as an almost immediate reaction. As areas with permafrost are very often located outside of settlement and infrastructure areas, the future risk is also limited. In critical areas, risks and damages can be minimised by the expansion of protective measures (e.g. safety nets, protective walls, monitoring).

At lower elevations, which will be exposed to positive temperatures more frequently due to the temperature increase, a reduction in the number of rockfalls is imaginable.

Engineering works

Engineering works, such as bridges, tunnels and passages, are not expected to be affected by constructional problems in connection with global warming. The magnitude of the temperature increase will normally be able to be absorbed by the works without consequence. Storms are not expected to cause structural problems either. An increase in potholes and flow problems near bridges and passages as a result of larger floodwater amounts is possible.

Contact wires and tracks

Winter storms

Based on the expected increase in winter storms, an increase in falling trees is to be anticipated (fig. 6). When trees fall on contact wires or tracks, this normally causes delays and the interruption of railway services, as well as damage to infrastructure. About one third of the 300-km-route network of the SBB is forested on one or two sides.

The SBB aims at a defined forest profile along all forested route sections. In the vicinity of the tracks, small bushes and scrubs are preferred, and with increasing distance more highly growing trees, so that a clear profile is generated. Thus, falling trees can rarely cause damage anymore. This procedure is beneficial with regard to availability and safety in case of storms but less favourable with regard to the shading of train embankments in the event of heat waves (microclimate of embankments).

Temperature trend/Extreme heat

The increase in summer temperatures affects the railway system. High temperatures lasting for days can result in lateral displacement of the tracks. This happens because expansion of the tracks due to the heat is blocked by the seamless welding. The resulting compressive forces can lead to lateral displacement of the tracks. When the tracks are laid, measures are taken in order to reduce these compressive forces and to increase the lateral resistance of the tracks.

During the heat-wave summer of 2003, lateral displacements occurred about 50% more frequently than is the case during an average summer. In order to avoid the risk of derailing, trains need to reduce speed in the event of lateral displacement or, in extreme cases, are no longer able to ride the tracks concerned. Since heat waves will have become considerably more likely by the year 2050, railway companies need to prevent more frequent lateral displacements. Construction methods can be adapted with some extra costs, so that the tracks withstand higher temperatures without damage. Thus, the requirements for Ticino are already more strict today. The tracks are exposed to higher

Figure 6: Tree over the trackway, Wiggen
(Photo: SBB)

temperatures during laying in order to prevent any later deformation.

Increase in summer storms?
Summer heat-storms also present a potential risk to contact wires because lightning strikes can lead to operational disturbances and damage to contact wire systems. Since there have been no forecasts with regard to summer storms up to now, it is hard to estimate whether this risk will change.

Development of loss amount
According to a study by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), which shows the development of loss amounts from 1972–2005, the cumulative cost of damage due to floods, landslides and mudflows have risen almost linearly with time over the past 30 years (fig. 7). The report shows that the increase in the cumulated loss amount is clearly sub-proportional in comparison to population growth, increase in settlement area and value concentration. Therefore, the extent of loss due to natural hazards is smaller than one would actually expect from the development of value concentration. This trend is not least attributable to the effects of the protective measures. In view of the expected changes, it seems probable that an exponential increase in loss amounts due to property damage can be largely avoided by anticipatory planning and the implementation of corresponding measures.

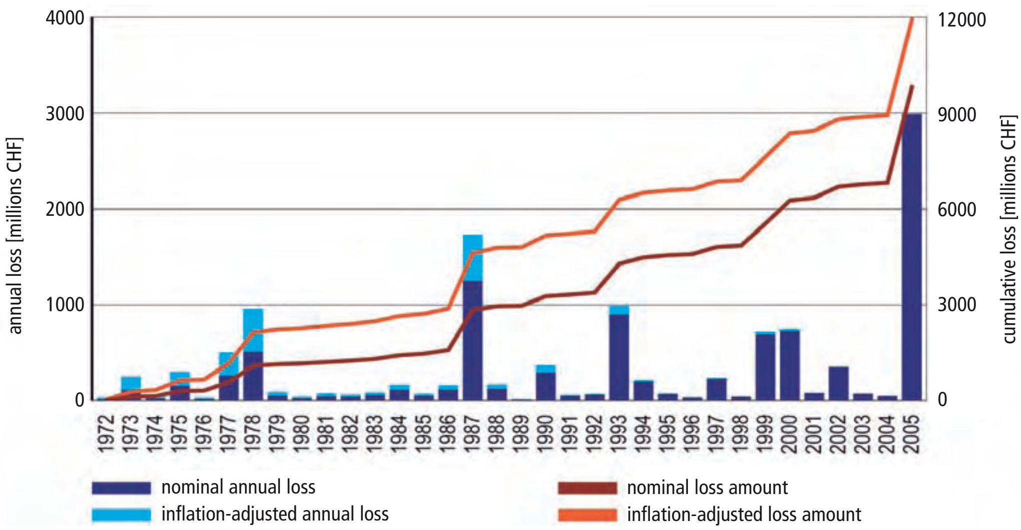

Figure 7: Loss amounts 1972–2005. Floods. Landslides. Mudflows.
(Source: Swiss Federal Institute for Forest, Snow and Landscape Research, 2007)

Road network

Similar to the railway system, the road network is also primarily at risk from extreme events. With preventive measures for new hazards and with adaptations in road making, disturbances and risks to road traffic will be kept largely constant.

Climate change will affect the road network in a similar way to the railway system. Fundamentally, it is expected that the extent of the effects on roads will be smaller because the road network is generally less sensitive as far as construction is concerned. Other factors, such as a further increase in the maximum weight of lorries or a distinct increase in the number of heavy vehicles, would in all likelihood have more severe effects than the expected climate change. Furthermore, the very dense road network has the advantage of being more flexible in comparison to the railway system; when a section of road is at risk or not passable anymore, alternative routes often exist.
Road making will adapt to changed conditions where necessary in relation to materials used and the construction of roadways. The most important climatic impacts on the road network will be floods and slope instabilities. In addition, avalanches, winter storms and hail may have adverse effects on road traffic.

Heavy precipitation/Floods

Floods can affect sections of roads in a similar way to railway lines. If rivers and lakes burst their banks, excessive volumes of water may cause undercutting or, in flatter areas, floods (fig. 8). In mountain areas, heavy precipitation often results in landslides and mudflows. On the other hand, low-snow winters may have a positive effect on road traffic, with a decrease in accident risk and costs for road maintenance.

Slope instabilities

Just as with rail traffic, there is a risk of mudflows and rockfalls for road traffic. Roads at higher elevations and in exposed positions are particularly at risk. Rockfalls are not necessarily attributable to climate change but can have various causes. Trigger factors include: rock weathering, larger water masses that act as a lubricant, frost/thaw effects that lead to the loosening of the rock formation, and the melting of permafrost due to increasing temperatures (see Line stability and security). A combination of different factors is also possible. Already today, the vulnerability of the traffic system to disturbances is great due to the large volume of traffic and people's expectation of almost unlimited mobility.

Avalanches

Just like the railway system, the road network may be affected by avalanches or avalanche risk. In conjunction with climate change, the risk will possibly increase at higher elevations, where larger precipitation amounts may fall as snow in winter.

Winter storms

Due to the expected increase in winter storms, falling trees will be more common. If these trees fall on the street, this puts drivers directly at risk and can lead to interruptions in road traffic. However, the risk is currently small and should not increase substantially in the future.

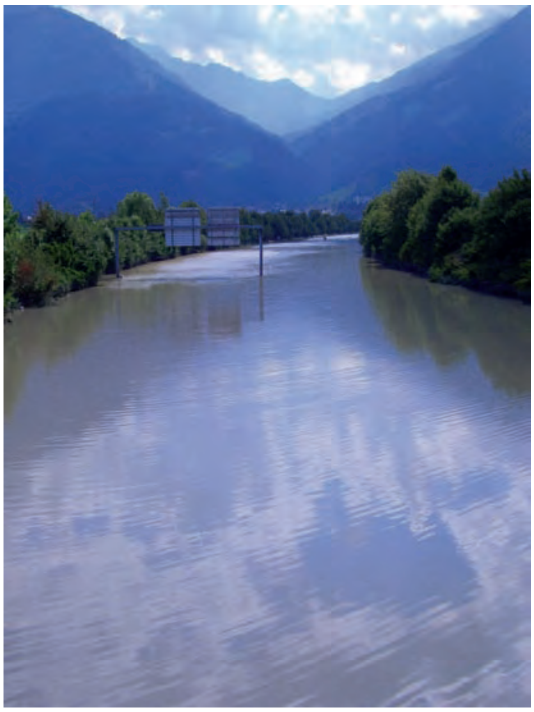

Figure 8: August 2005, N8, between East Interlaken and West Interlaken.
(Source: Muriel Kleist)

4. Urban water management

In order to ensure the water supply, warmer and drier summers on the one hand, and changes in water demand on the other, require that water management be optimised. Sewage disposal has to be adapted to the changing requirements due to higher temperatures, as well as more frequent dry spells and heavy precipitation events.

Water supply

With climate change, the demand for premium quality water (drinking water quality) will increase. This will require that water management be improved, in particular because there will be an increase in the variation of consumption. Additional peak consumptions could occur if more people spend their holidays in Switzerland in the summer months instead of going to the south, where it will be hotter in the future.

Dry summers will strongly increase the water demand for watering gardens. Water of lower quality can be used for this purpose, although appropriate infrastructure does not currently exist. The heat-wave summer of 2003 gave an indication of the extent of the expected demand. Since groundwater is rarely used to capacity today in Switzerland, and because there are sufficient water reserves in the lakes, it should be possible to cover additional peak consumptions, provided water supply infrastructure is adequately linked. However, temporarily falling groundwater levels are expected to occur regionally. Groundwater contamination due to the discharge of pre-cleaned surface water into the subsoil will become more frequent. Groundwater protection zones may need to be enlarged. This will mean considerable financial expense, since the setting aside of protection zones involves expropriation procedures.

Water provision from springs is critical in rural, poorly linked karst areas (Jura, Alp foothills) if springs with small catchment areas fed by surface water run dry during prolonged dry periods. In order to ensure water supply here as well, a stronger linked network is necessary, which will be associated with high costs.

With higher temperatures, water temperatures will also increase. This could possibly become uncomfortable in Switzerland but still not critical. The quality of raw water, of which 20% comes from lakes and 80% from groundwater and springs, could worsen in certain cases. A change in algae population and therefore in oxygen content would require new preparation processes. The danger of microbial recontamination in distribution pipelines will increase.

Sewage disposal

Sewer system

Higher temperatures in the sewer system due to higher outside temperatures will lead to increased concrete corrosion and therefore increase the need for maintenance. This problem can be avoided by choosing appropriate materials. Odour problems may possibly occur more often.

If the groundwater level falls during dry periods, the infiltration of groundwater decreases. At the same time, the exfiltration of sewage water increases. This increases the sedimentation in sewers and possibly pollutes the groundwater as well. Dry phases also affect the treatment of mixed water, that is, rainwater mixed with sewage water, which cannot be taken up by sewage plants due to capacity constraints. If dilution can no longer be ensured in small rivers due to low water flow or drying-up, the demand for treating mixed water may increase. Additionally, tractive forces in sewer lines decline with a decreasing proportion of foreign water, which increases the risk of blockages and requires adaptations in the operation of sewage plants.

On the other hand, heavy precipitation can lead to backwater in sewers and thus to flooding of cellars or entire neighbourhoods. With the expected increase in heavy precipitation, this problem will occur more often and, in critical cases, require the laying of larger dimensioned sewer pipes and installation of backwater valves.

Wastewater treatment

Climate change poses little threat to the wastewater treatment operation, however, certain adaptations will be necessary. Biological processes accelerate with increasing temperatures and oxygen demand rises as a result. Since oxygenation will be hindered at the same time, facilities will need to be upgraded.

Higher temperatures of waterbodies, low water due to increasing aridity and the greater demand for irrigation water will result in additional demands on wastewater treatment. Such investments may also be required by the demand for higher standards of water for bathing.

Private house connections

With both sewer systems and water supply, problems primarily occur at the house connections. In Zurich, this is the case for 50% of water pipe ruptures. If the groundwater level falls as a result of climate change, this may result in settling, which, in turn can cause more frequent pipeline ruptures.

Uncertainties/Open questions

The effects of climate change on urban water management can only partly be assessed. In order to assess more precisely where there is indeed a need for action, additional hydrological information is required, in particular on the development of groundwater levels, the frequency of short and heavy precipitation events, future water supply, the frequency of extremes and the seasonal cycle.

5. Urban settlements

In cities, the heat load is larger than in the surrounding area due to the larger proportion of sealed surfaces, less numerous green areas, waste heat from buildings, industry and traffic, and poor air circulation. With climate change, the problem of urban heat islands will increase.

Cities are often cooler during the day than the surrounding area but significantly warmer during the night. Different factors contribute to the so-called "heat island" effect and therefore to the generally higher heat load in cities. Buildings and sealed surfaces absorb more heat than ground that is not covered. The heat input during the day is stored by roads and buildings, and the cooling effect due to evapotranspiration is small in comparison to the surrounding rural area because green spaces and plants are rare. Additional heat comes from the emission of waste heat by buildings, industry and traffic. Finally, air circulation in cities is worse than in the surrounding area due to the reduced wind speed.

Temperature increase and more frequent heat waves or heat periods worsen the problem of urban heat islands. Thus, the effects of the heat wave summer of 2003 were distinctly more serious in cities than in rural areas.[12] Temperatures reached particularly high values, which meant that the mortality rate amongst inhabitants of cities was especially high.[13] With regard to health effects, it is not only the maximum daily values but also the high nighttime temperatures that are relevant. In view of the expected development that with climate change there will be a stronger increase in nighttime than daytime temperatures, countermeasures are particularly important. Since nighttime temperatures in cities are already generally higher today, the negative health effects will worsen with climate change.

In Switzerland, the increased heat load in cities has been neglected so far in urban development. This aspect needs to be considered in spatial planning in order to prevent the heat load resulting from climate change from increasing further for urban dwellers. Thus, for instance, greening and shading of pavements and pedestrian zones can reduce the heat load.

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Urban Switzerland

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1. Introduction

Background

Switzerland is an urbanised country, that is, urban and rural areas are closely linked by dense flows of people and goods. It is this network, consisting of nodes and fluxes, that forms the urban system. The development of this system depends on numerous factors. Climate is just one of many cultural, political, economic, spatial and ecological factors. How strongly and in what way the expected climate change will affect settlement development, depends on the future form of the Swiss urban system. As a basis for the following assessment, three possible scenarios were chosen, for which the impact of climate change is described by means of six key factors:

1. Today's system as the reference state: CH_{today}.

2. A scenario based on the assumption that adaptations that have already been introduced will continue: $CH2050_{plus}$.

3. A scenario based on a change of policy according to the criteria of sustainable development: $CH2050_{eco}$.

The key factors are as follows:
1) Population
2) Settlement pattern
3) Building stock (inventory of buildings and infrastructure)
4) Transport and communications
5) Resources
6) Relationships within Switzerland and with foreign countries.

Overview

Population development will presumably be little affected by climate change. The change in the demographic structure will take place independent of climatic changes. Immigration pressure will probably increase if economic conditions worsen considerably in other countries due to climate change.

Settlement development will occur largely independent of climate change, except in mountain areas. These are under pressure to adapt due to the threat of natural hazards and the dependency on winter tourism. Settlement development in regions exposed to floods will be less affected.

The impact of climate change on *building development* is categorised as marginal. Here, the development depends primarily on the business cycle. Further substantial growth is expected by the mid-21st century.

The expected development of the *transport and communication* sector differs according to scenario. In the $CH2050_{plus}$ scenario, traffic will continue to increase, whereas in the $CH2050_{eco}$ scenario, the growth trend will come to a standstill. The $CH2050_{eco}$ scenario, with its changed settlement pattern with strengthened regional centres, will be less vulnerable towards climate change than the $CH2050_{plus}$ scenario.

Climate change will affect the *availability of resources* primarily with regard to the degree of self-sufficiency in food production and energy supply. In the $CH2050_{plus}$ scenario, the degree of self-sufficiency will decline for food and slightly increase for energy supply. In the $CH2050_{eco}$ scenario, a massive increase in the degree of self-sufficiency is expected for food and a small increase for energy supply.

The development of the *relationships with and dependencies on the global setting* are particularly decisive for the functioning of the Swiss urban system with regard to food and energy supply. Depending on the impacts of climate change on other regions, as well as global political changes, prices could increase substantially in both these sectors.

Altogether, the Swiss urban system as a whole is not endangered by climate change. Local and seasonal disturbances may be enhanced due to the impacts of climate change on other regions of the world. In comparison to the $CH2050_{plus}$ scenario, the $CH2050_{eco}$ scenario is more robust.

2. Switzerland as an urban system

Switzerland is an urbanised area that is influenced by cultural, political, economic, spatial and ecological factors. Thus, climate change represents just one of many factors.

Switzerland is a densely populated country with a mean population density of 180 inhabitants per square kilometre. The majority of the population lives in urbanised space, i.e. in a network that links urban and rural areas by strong flows of people, goods and information (fig. 1). This network, whose nodes (cities) are characterised by a high density of people and goods, is called an *urban system*. Thanks to this system, a high-quality of basic supply in Switzerland has been attained, and also a high level of security in the case of strongly varying environmental conditions (temperature, light, availability of resources) and natural hazards.

In Switzerland, urban forms of living have very different characteristics depending on the region. This is due to the fact that every urban development is shaped by the complex interaction of different factors, with cultural, political, economic, spatial and ecological factors determining settlement development. These factors can be external effects (exogenic, e.g., transport policy of the European Union, development of communication technology) or effects within the urban system (endogenous, e.g., business location decisions, development of gross domestic product). Global warming is therefore just one of many factors that affect the urban system. The strength of the impact on urban development depends on the regional characteristics and the development dynamics of the system concerned. These changes cannot be reliably predicted to the year 2050, although there are normative guidelines provided by the state (legislation, laws, regulations) and overall concepts from interest groups on how a country should look in 50 years. The following assessment is however not based on overall concepts but on scenarios. The climate scenarios for the year 2050, which show the expected change as well as the range of uncertainty for climate change, are applied to three possible scenarios of urban development in Switzerland (reference state CH_{today}, $CH2050_{plus}$, $CH2050_{eco}$, table 1). The questions that follow will be answered for each of these three scenarios.

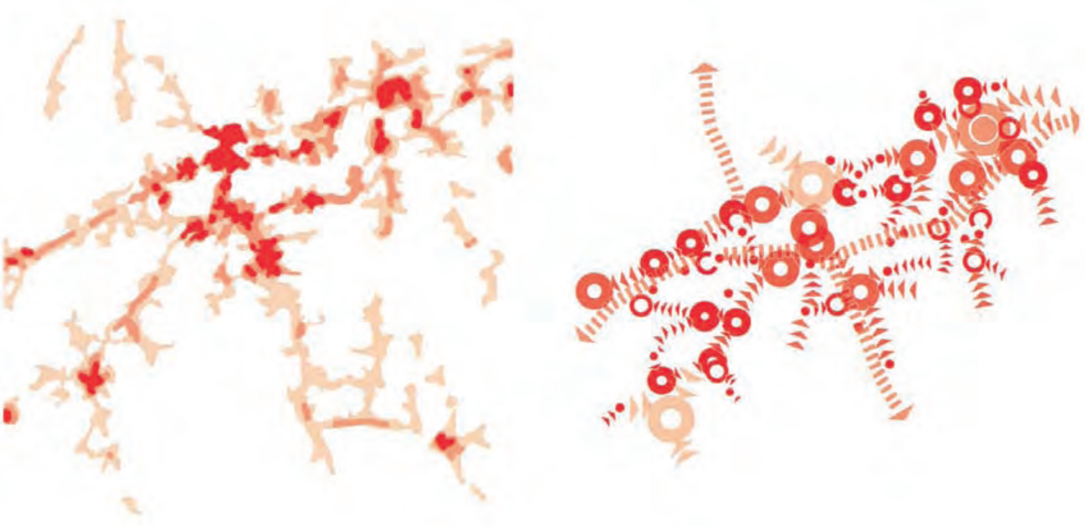

Figure 1: Graphic interpretation of the architecture of the territory according to the Netzstadt model:
- the web-like settlement structures and patterns (nodes and connections), using the midlands as an example (left)
- the fluxes (people, goods and information) within the web-like settlement structure, using the midlands as an example (right)

(Source: Oswald and Baccini 2003)[1]

In which areas is the urban system as a whole or part

a) robust, i.e. climate change is presumably irrelevant?
b) disturbed, i.e. adverse effects are possible but the functioning of the system as a whole is hardly at risk?
c) at risk, i.e. climate change endangers essential parts and therefore the system as a whole?

Other topics of the project "Climate change and Switzerland in 2050" are also considered to be subsystems of the urban system: Land ecosystems, Agriculture, Water management, Energy, Buildings and infrastructure, and Tourism (see corresponding chapters).
The majority of the following statements relating to the above-posed questions are qualitative. Quantitative statements are difficult because there are no reliable model results for urban systems. In contrast to the climate scenarios calculated with the help of physical models, the three urban development scenarios are based on six selected key factors: population, settlement pattern, buildings, transport and communications, resources, and relationships within Switzerland and with foreign countries. The impact of climate change in 2050 on the three scenarios of urban Switzerland is estimated by means of these key factors.

3. Scenarios and key factors

The impact of climate change on the Swiss urban system will be illustrated using the three scenarios. Today's state serves as the reference scenario. Scenario 2 describes a further development analogous to today's state, and scenario 3 is a change of policy towards sustainability (see table 1). Six key factors are used (see table 2).

Table 1: Possible scenarios of urban development in Switzerland up to the year 2050.

Scenarios	CH_{today} [1)]	$CH2050_{plus}$	$CH2050_{eco}$
Short description	Reference state, in order to estimate possible effects on today's existing system	Continuation of the development of the last decades, taking into consideration adaptations that have already been introduced	Change of policy according to the criteria of sustainable development[2)]

1) Relates to the year 2005, as far as numbers are available.
2) In the energy sector, this scenario has as its goal the 2000-Watt society, i.e. a reduction in energy consumption to one third of today's amount, as well as the extensive replacement of fossil fuel by renewable energy.

Table 2: Key factors for describing the urban system.

	Identifier	Characteristics
1	Population	population, age structure, ratio labour force/total population
2	Settlement pattern	population densities/distribution according to regions
3	Buildings	state and development of buildings and energy demand
4	Transport and communications	development of passenger transport and goods traffic, and of the communication sector
5	Resources	degree of self-sufficiency for basic resources such as water, energy, food, building materials
6	Relationships and interactions	domestic relationships: midlands vs. mountain areas; international relationships: dependencies on foreign countries

Possible changes in political institutions, such as the number and structure of administrative units (municipalities, cantons) and memberships in international bodies (e.g. European Union), are not taken into consideration. It is assumed that such changes are possible within both future scenarios ($CH2050_{plus}$ and $CH2050_{eco}$). Catastrophic economic, warlike and geologic incidents are not taken into consideration. Basic information on the scenarios chosen can be found in Baccini and Bader (1996)[2], Baccini and Imboden (2001)[3], Baccini et al. (2002)[4] and Leibundgut (2006).[5]

4. Population development

Quantitatively, the mean growth of the population will not present any new challenges. What will be important, however, are population aging and the reduced labour force. This will result in a change of spatially related utilisation demands.

Table 3: Parameters of population development[6]

Parameter	**Scenarios**		
	CH_{today}	**$CH2050_{plus}$**	**$CH2050_{eco}$**
Inhabitants (millions)	7.4	8.2[1)]	8.2[1)]
Old-age quotient[2)]	25	51	51
Overall employment rate[3)]	56	51	51

1) medium scenario (i.e. between 9.7 and 6.5 million)
2) old-age quotient: Number of people aged 65 and older per hundred people aged between 20 and 64.
3) overall employment rate: Number of people in the labour force per hundred people aged between 15 and 99.

The considerable change in the old-age quotient from 25% to 50% (Table 3) points to a shift in the age distribution, which will also mean drastic shifts in the framework of the social insurance system (old-age and survivors' insurance (AHV), company and private pensions, health care system). The inter-generation contracts established in the 20th century will most likely need to be strongly revised. The increasing ageing of the population should affect today's distribution and design of the living and working environment, as well as mobility, that is, today's building stock in Switzerland (see section 6) will also need to adapt to changed conditions and requirements.
The negative impacts of climate change mentioned in the Health chapter will probably have little effect on the population distribution. Climate change should also hardly have a strong influence on the change in the demographic structure. However, the possibility cannot be ruled out that immigration pressure will increase if economic conditions in other parts of the world take a long-term turn for the worse due to climate change.

Conclusion

A mean growth rate of the population of 0.3% per annum with a mean increase of the total population of about 14% will not quantitatively present any new challenges to the Swiss urban system. However, the shifts in the old-age quotient and overall employment rate will be important. These qualitatively grave changes in the demographic characteristics as compared to today will be highly relevant for future spatially related utilisation demands.

5. Urban development

Today, a large proportion of the Swiss population lives in cities and agglomerations. An important factor for the future development of the urban pattern is the steadily growing demand for settlement areas.

CH_{today}

In Switzerland, the settlement structure is considerably influenced by topography. Originally, settlements developed along waterbodies or commerce routes in the valleys and midlands and on the Jura plateau. They formed the points of origin for progressive settlement, which have since covered large areas all over the country with buildings and infrastructure. However, this urbanisation has not developed evenly throughout. Various factors, from industrialisation, the development of the railroad network, individual motorisation, and the development of air traffic to the modern means of communication, have contributed to the non-uniform development. With just a few exceptions, rapid increases in urbanisation were related to changes in lifestyle, very often in combination with changes in the areas of mobility and communication.

Particularly after the Second World War, economic growth led to an exponential settlement growth between the urban centres of the 19th century. This growth was not primarily caused by population growth but by the increasing demand for settlement area per capita and the increasing traffic area per capita. This process is still incomplete even now at the beginning of the 21st century. In about thirty years (1950–1980), the number of motor vehicles for passenger transport had increased tenfold. Lifestyle changed as a result of high individual mobility.

Today's urban structure thus generated is called Netzstadt and integrates areas used for agriculture, forestry and water management (fig. 2). In the midlands, the actual proportion of the settlement area is between 10 and 15% of the total area. Agriculture accounts for about half of the total area, and forests one-third. Considerably more than 75% of the Swiss resident population live and work in cities and agglomerations.[7] This shows that accessibility, development and the vicinity of urban attractions are particularly important criteria for the choice of where to live and work.[8] The development of real estate prices in the large agglomerations of Zurich and the Lake Geneva area reflects these preferences. Increasingly, areas are built on and settled that were little favoured as locations up to now. This statement is true for all of Switzerland but to an even greater extent for the urban areas in the pre-alpine and alpine regions.

There are tourist locations in the alpine region that have experienced strongly accelerated urban development that is particularly related to the expansion of winter tourism. Here in the past, it was assumed that the climate would remain constant, thereby ensuring reliable snow conditions (fig. 3).

Figure 2: Large-scale photograph with Kloten, Wallisellen, Opfikon, Hard (2004): The web-like structure between the municipalities is clearly visible (Source: Swiss Air Force).

Figure 3: View over Lake St. Moritz to the village St. Moritz (south-east elevation), the mountain range with Piz Nair, Sass Runzöl and Las Trais Fluors in the background, general view, reconstructed photo, in 1899 (above) and 1996 (below).
(Source: Stiftung documenta natura, Bern)

CH2050$_{plus}$

If the population development in table 1 is combined with the still steadily increasing urban area per capita of today of 400 m^2 per capita to about 470 m^2 per capita by 2050 (growth rate up to now: about 1.3. m^2 per capita and annum, see fig. 4), a total increase in urban area (i.e. with the land-use demands for the proportional increase in infrastructure requirements) of about 30–40% is to be expected. In this scenario, this growth will certainly be larger than the potentially decreasing demand for workspace due to the lower employment rate. Though the additional demand for settlement area is already nominally covered with regard to today's designation of building zones, the regional distribution does not conform to the demand or the targets of spatial planning. In the CH2050$_{plus}$ scenario, there will be too little high-density housing built in already existing settlement areas due to the absence of or false incentives. The settlement pattern represented in the CH$_{today}$ reference state will therefore be further strengthened, that is, existing nodes and links will be enlarged in area, in fact by about 30%. In the midlands, the proportion of settlement area would increase to about 15 to 20%, at the expense of the most productive agricultural land in Switzerland, of which the total area would decrease by about 10%.

This development will be different in different regions, due to the economic advantages of location of large agglomerations, and the availability of infrastructure and real estate. The densely populated urban areas of the midlands, the region around the border triangle of Basel, the lake Geneva area and Ticino, which is strongly shaped by the development in upper Italy, will be particularly affected by the increasing demand for settlement area. It can be assumed, furthermore, that in the mountain areas of Switzerland, as well as of other parts of Europe, the demand for holiday homes will increase due to the desire for summer retreat (see Tourism chapter, section 6).

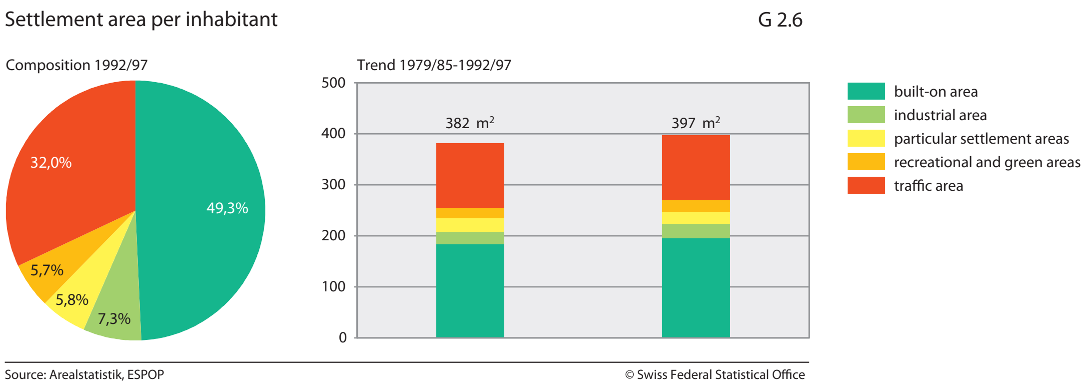

Figure 4: Land-use statistics divide the urban area into five kinds of use: built-on area, industrial area, traffic area, particular settlement areas, and recreational and green areas. The built-on area dominates the settlement area with a proportion of almost 50%.
(Source: Arealstatistik Schweiz, Zahlen – Fakten – Analysen, Federal Office for Statistics BFS, 2005)

CH2050$_{eco}$

An urban settlement structure that conforms to the criteria of sustainability offers more varied design possibilities compared to today's settlement patterns. According to the quality targets of the Netzstadtmodel[1], the existing pattern will need to be revised or adapted with regard to the following areas: The effectiveness of the spatial planning instruments (federal plans, cantonal directive plans, municipal zoning plans) needs to be even more strongly adjusted to the targets of the entire spatial development (spatial concept Switzerland) and the imperative of economical land use and well-regulated settlement development.

- With a strengthening at the regional level, the possibilities for satisfying material and non-material needs must be improved. In this way, the quality of life can be maintained or even increased in spite of a decrease in traffic volume.
- On the national level, the trend towards further spatial expansion of the large agglomerations must be stopped. Strong regional centres of different quality will mean more diversity and therefore a more robust Swiss urban system.
- If agriculture, forestry and water management are carried out according to sustainability criteria, smaller earnings in comparison to today are partly to be expected (about 10%), which, however, can be compensated by other measures (see sections 6, 7 and 8).

These adaptations in settlement development would lead to considerable structural improvements on the regional and municipal level.[1] On a national level, the basic structure of the settlement pattern would still not change substantially.

Conclusions

Altogether, the effects of climate change on urban development to 2050 can be considered to be rather small. Vulnerability will be highest in the alpine area, which strongly depends on tourism (see Tourism chapter, section 4), and for buildings and facilities of the rail and road networks, which are particularly exposed to natural influences. Settlement areas that are located in the immediate vicinity of waterbodies will also be affected to a limited extent. It can be expected, however, that the adaptations that are continuously being implemented due to the increased danger potential that is already recognised today (e.g. building restrictions based on risk maps, expansion of watercourses, local shifts in settlement development) will be successful. Altogether, the potential for conflicts between the demand for land for settlement development and other (utilisation) interests will be smaller for the CH2050$_{eco}$ scenario because the aim is a concentration of existing nodes and connections, rather than a further expansion in land use.

6. Development of building stock

If climate change is consistently and anticipatorily taken into consideration for renovations and new buildings, the impact of climate change on the Swiss building stock will be marginal.

The parameters for the Swiss building stock are compiled in table 4.[9]

Table 4: Stock and energy flux of the Swiss urban system.

	CH_{today} 1)	$CH2050_{plus}$	$CH2050_{eco}$
Stock in tons per inhabitant 2)	400	500	450
Energy demand in watts per inhabitant 3)	6000	6000	2000

1) reference year 2000
2) comprises buildings and infrastructure
3) includes the energy brought in with imported goods (embodied energy)

Today's building stock corresponds to a replacement value of about half a million Swiss Francs per inhabitant. In the $CH2050_{plus}$ scenario, this stock will increase by about one quarter. From an economic perspective, this means that the generation after the next will have to generate more capital per capita in order to ensure the conservation of value of its real estate. In the $CH2050_{eco}$ scenario, growth will be smaller because infrastructure is optimised (see section 5) and passenger transport is strongly shifted to the railway system. Thereby, the increase in civil engineering will be smaller. With regard to energy demand in the $CH2050_{plus}$ scenario, the measures already taken (e.g. building regulations, taxes on fossil energy sources, promotion of renewable energy) will result in an approximate compensation of the increasing demand by increased energy efficiency. In the $CH2050_{eco}$ scenario,the focus will be on a consistent modification of energy technology in combination with the systematic adaptation of building and transport technology. This scenario aims at reducing the proportion of fossil energy sources in today's primary energy demand of about 5500 watt (including nuclear energy sources) to about 500 watt per inhabitant.[10] The adjustment of the energy budget, which is determined to 80% by living and working activities, transporting and communicating (see section 7), will be the key process in this scenario.[3]

Conclusion

The impact of climate change on the Swiss building stock will be marginal for both scenarios, provided that climate change is taken into consideration for renovations and new buildings (see Buildings and infrastructure chapter, section 2). In highly developed countries, the development of the building stock depends on the economic cycle, that is, the higher the economic growth in the most important branches of value creation, the more active the building activity. However, this framework can be changed by means of political regulations and incentives in such a way that the effects of new environmental influences (e.g. climate change, availability of resources, traffic congestion, traffic noise burden) can be identified at an early stage and reduced in the name of prevention, if reasonable.

7. Development in transport and communications

Disruptions to traffic routes and long-distance power lines may possibly increase with more frequently occurring extreme events. An ecologically oriented development reduces the sensitivity through concentrated nodes and lower energy consumption.

CH_{today}

In the past decades, the transport of passengers, goods and information has gradually increased, as measured by distances covered per capita and per annum (see fig. 5). Passenger transport accounts for the largest proportion (70 to 80%), while information flow amounts to just a few percent. Transport is the most important factor with regard to atmospheric and noise load. Up to now, the reduction targets could only partly be met in spite of engineering (e.g. catalysers for combustion engines) and construction (e.g. noise barriers) measures.

$\text{CH2050}_{\text{plus}}$

The increasing number of vehicles per capita and kilometres covered per vehicle and annum will increase the negative effects on the environment (air, noise) and the economy (congestion costs). Though traffic congestion can, with a time lag, be solved locally by means of road extension projects, it will be shifted to other bottlenecks within the Swiss Netzstadt. The expansion of metropolises and the increase in private passenger transport will reinforce each other. Although the expansion of public transport can reduce the growth of individual motorised traffic, it cannot solve the related problems that already exist.

$\text{CH2050}_{\text{eco}}$

In contrast to the $\text{CH2050}_{\text{plus}}$ scenario, the traffic growth trend will come to a standstill in the $\text{CH2050}_{\text{eco}}$ scenario.[11] Inward settlement development and strengthening of the regional centres will mean that the distances covered become shorter because they are matched to the appropriate activity (e.g. working, shopping, recreational activity). However, these changes will only be realisable with a reorganisation of the Netzstadt, that is, the entire settlement pattern (see Netzstadt model by Oswald and Baccini[1]) and not with purely traffic-related measures.

Conclusion

Climate change will not have a significant impact on transport and communications because the problems related to these areas little depend on external influences. An exception is the energy supply (see sections 8 and 9) and the interruption of traffic routes due to extreme weather events. The vulnerability with regard to interrupted traffic routes will be smallest for the $\text{CH2050}_{\text{eco}}$ scenario, due to concentrated nodes.

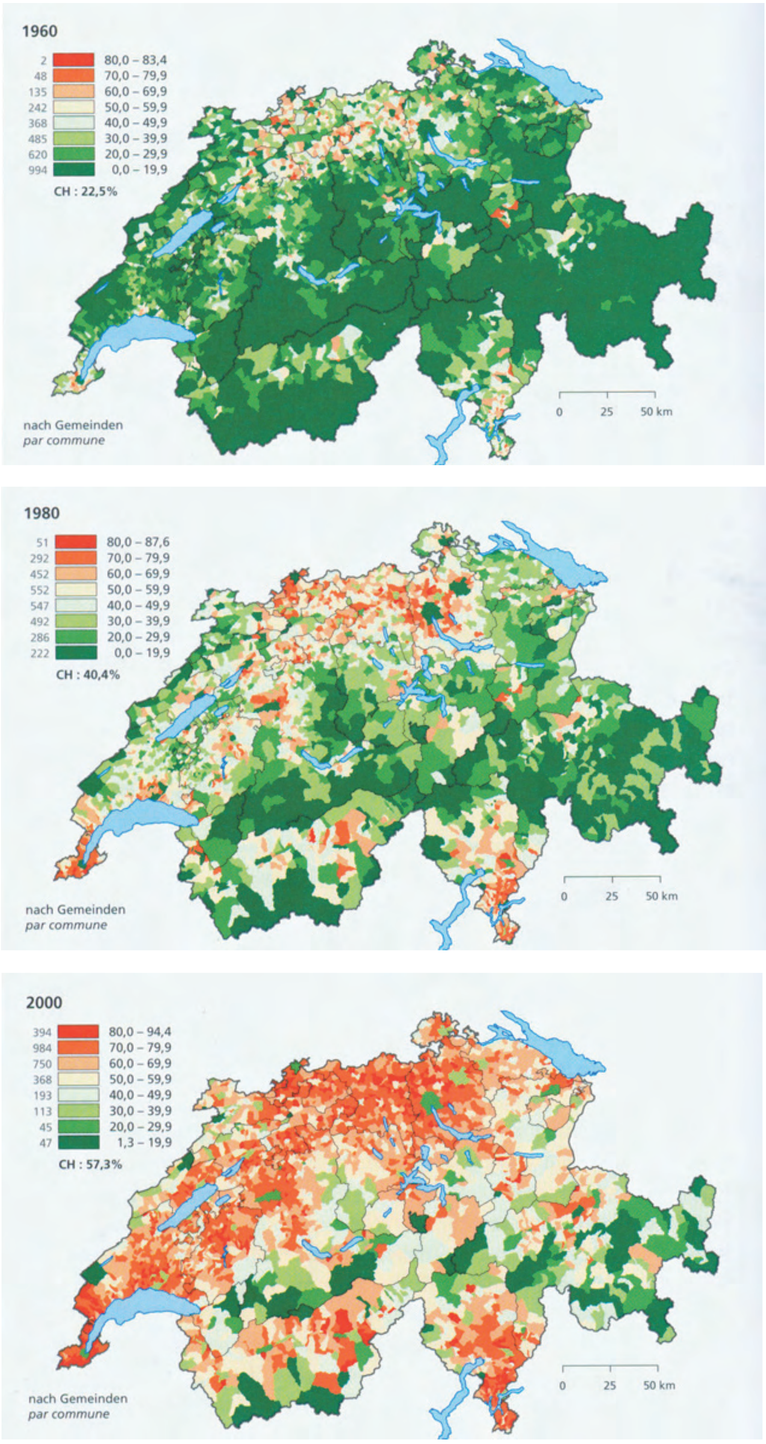

Figure 5: Development of commuter flow between 1960 and 2000: The proportion of the labour force working outside their municipality of residence (in %) is mapped for 1960, 1980 and 2000, respectively.

Green areas correspond to a small proportion of the labour force working outside their municipality of residence (<40%). Red and orange areas correspond to a proportion of 60% or more of the labour force working outside their municipality of residence.

Proportion of commuters:
1960 CH: 22.5%
1980 CH: 40.4%
2000 CH: 57.3%

(Source: Schuler, Martin et al. Atlas des räumlichen Wandels der Schweiz, Bundesamt für Statistik, Neuchâtel und Verlag Neue Zürcher Zeitung, 2006. S.268)

8. Development of resource availability

The Swiss urban system is most strongly at risk due to the non-sustainable energy supply. As a global phenomenon, climate change increases this risk because other regions are also affected.

Table 5: Resource availability of the Swiss urban system shown by means of a theoretical degree of self-sufficiency.[2] The theoretical degree of self-sufficiency describes the ratio (in mass or energy units) of the total domestically produced amount (in %) to total consumption, i.e. import and export are offset against each other as exchangeable components in the point balance. In view of the variation in quality, this is a strong simplification. Thus, the numbers are to be understood as orders of magnitude only.

Resources	**Scenarios**		
	CH_{today}	**$CH2050_{plus}$**	**$CH2050_{eco}$**
Water	100	100 (seasonally and regionally disturbed)	100 (seasonally and regionally disturbed)
Biomass	60 (food) 100 (wood)	40 (food) 100 (wood)	80 (food) 100 (wood)
Building materials	90	70	100
Energy sources	10	20	90

CH_{today}

In the CH_{today} scenario, the Swiss urban system is autonomous with the already existing water supply infrastructure. For bulk materials of the building sector (gravel, sand, clay), which account for almost 90% of the overall mass of the building stock, the theoretical degree of self-sufficiency (DSS) is high. Forestry legislation requires sustainable forest management. For economic reasons, forests are only used to about 70% today. Extreme events, such as storms leading to forest damage, result in local disturbances and lead to a temporary oversupply of wood. In the food industry, the DSS of 60% is primarily a consequence of the population's diet, that is, the higher the meat consumption, the lower the DSS. With regard to energy supply, DSS is the lowest because the urban system in the 20th century was consistently oriented to fossil sources in the global market. There, the DSS is presently at 10%, of which the main part is provided by the use of water power for electricity production.

$CH2050_{plus}$

For the $CH2050_{plus}$ scenario, the picture will remain largely the same. According to the Water management chapter, climate change can lead locally and seasonally to bottlenecks in supply (see Water management chapter, section 4). In the food industry, DSS will decrease because the continuation of agricultural policy will force producers to compete in the unprotected market by means of niche products. Increases in energy consumption efficiency that have already been introduced and investments into water power, solar sources, geothermal and wind power could increase DSS to 20%. This development will be influenced by climate change because reduced water supply is to be anticipated in the future (see Water management chapter, section 4).

$CH2050_{eco}$

In the $CH2050_{eco}$ scenario, DSS will increase for all four resources considered. For food, this will happen under the assumption that the regional supply will improve overall (see Agriculture chapter, section 2) and that, in addition, diet will change so that meat consumption per capita decreases. For building materials, DSS increases due to the wide-spread use of the new technology of "urban mining"[9], i.e. the recovery of raw materials from existing building stock. The energy sector will experience the greatest change, with DSS increasing massively (see also section 7). In the water power sector, climate change will impede this development due to the already mentioned reduction in runoff. On the other hand, climate change is a reason for an energy supply as low in CO_2 emissions as possible. Altogether, also in this scenario, the availability of resources primarily results from the politically and socio-economically shaped development.

Conclusion

The degree of self-sufficiency for food and energy will change for both scenarios. In contrast to the $CH2050_{plus}$ scenario, the degree of self-sufficiency in the $CH2050_{eco}$ scenario can be expected to increase slightly due to improved regional supply and altered diet. In the energy sector, the degree of self-sufficiency will increase more strongly in the $CH2050_{eco}$ scenario. On the one hand, climate change will affect this development by the change in water resources, and on the other hand, indirectly as a driving force behind the decarbonisation of the energy supply system.

9. Development of relationships and dependencies between the Swiss urban system and the global environment

Climate change is a global phenomenon. The Swiss urban system will therefore not only be affected directly but also indirectly as a result of the impacts on other parts of the world.

The proportion of income that households spend on food and energy is a critical factor with regard to the future functioning of the Swiss urban system. If this proportion is also smaller than 20% in the future, the availability of resources will presumably correspond to the numbers in table 5. However, there are climate change scenarios for other regions (subtropical, arid) in which the production of agricultural goods will decrease massively due to the changed water supply. As a result, the price for food will increase exponentially and also substantially change the household budget in Switzerland. The availability of energy from fossil deposits will hardly change as a direct result of climate change. However, should energy prices increase rapidly because of global political changes, the Swiss urban system does not yet have an alternative supply possibility. In this case, the prices could reach very high levels in countries with a low degree of self-sufficiency, i.e. level out within 10–20 years at the tenfold amount. On the other hand, the reconstruction process of the building stock (see section 6) for a $CH2050_{eco}$ scenario would take 30–60 years. Not until then would Switzerland be ready for such a situation.

Conclusion

From today's global political perspective, the Swiss urban system is most strongly affected by the non-sustainably oriented energy supply. This disadvantage may even increase, depending on the impact of global climate change on other regions.

10. Conclusions

When considered in isolation, the Swiss urban system is relatively robust with relation to climate change. A fundamental reconstruction towards targeted sustainable development will minimise the direct and indirect consequences.

For all three scenarios outlined, it can be said that the effects of climate change may disturb the Swiss urban system locally and seasonally (see conclusions of other chapters) but will not put it at risk as a whole. Thus, the system is relatively robust. If Switzerland develops towards the $CH2050_{plus}$ scenario, climate change will only slightly affect the handling of the deficiencies of the urban system. The non-sustainable energy supply (one-sided dependency on fossil energy sources), as well as the increasing building stock per capita (exponential increase in operating costs), will remain. The impact of climate change on other regions that are economically relevant to Switzerland could even increase these weaknesses.

The $CH2050_{eco}$ scenario shows the characteristics that the Swiss urban system should have in order to eliminate its weaknesses. As a small sovereign society, Switzerland would be – so to speak as a bonus – more robust to the direct and indirect consequences of climate change. Reconstructing Switzerland towards a $CH2050_{eco}$ state would require broad political support. Up to now, such a reorganisational process has only been an issue within a few academic groups, while in the political programmes of the Federal Council and the parliament, it is only in the modest beginning stages and is still far from implementation. From today's perspective, it therefore seems to be more likely that the Swiss urban system will continue to move towards the $CH2050_{plus}$ scenario.

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Insurance

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1. Introduction

Background

Changing climate affects almost all economic sectors and therefore almost all areas of insurance. Not only the insurance of buildings and contents, with coverage of natural hazards (storm, hail, flood, landslide, snow load, avalanche, rockfall, rock slide), is affected by climate change but also, amongst others:

- Agricultural insurance against crop failure due to hail, storm, flood, drought, frost or forest fire
- Automobile physical damage insurance against hail, flood or storm
- Business interruption insurance
- Loss of income coverage in the tourism and energy sectors, and in water management
- Health and life insurance coverage for the consequences of extreme events

In Switzerland, building and contents damage as a result of extreme events account for the largest share of total insured loss (table 1). This chapter deals with the impact of climate change on these two classes of insurance, as well as on reinsurance.

Overview

Over the past decades, losses due to natural hazards have increased worldwide and in Switzerland (figs. 1 and 2). This development is mainly due to socio-economic changes: Insured assets have increased, insured assets are increasingly located in exposed areas, the vulnerability of buildings has increased due to construction methods and choice of materials, and insurance penetration has increased. It is not clear to what extent climate change has contributed to the observed increase in losses.
Natural hazard scenarios will continue to change in the future due to societal changes and climate change, and the losses will increase. Early adaptations are required at different levels:

- Insurance and reinsurance companies need to be cost-effective in order to be able to pay damage claims. If claims due to natural hazards become greater and more frequent, premiums will need to be increased or the cover limited. In order to remain profitable with an increasing variability of natural hazards, insurance companies will, in addition, have to increase their capital or their reinsurance cover.
- If strong natural hazards become more frequent, preventive measures will have to be taken in order to make the risk insurable again. Adaptations and the enforcement of spatial planning regulations and standards for construction are the only effective long-term measures against increasing losses due to natural hazards. Insurance and reinsurance will continue to cover losses due to rare events.
- Currently, the insurance industry is developing new products that enable frequent and intense loss events with a high variability to be dealt with. Cat bonds are a first approach, however, their market share is still very small in comparison to traditional insurance and reinsurance.

It is important that the scientific findings regarding the possible consequences of climate change, in particular of extreme events, are already now included in risk models for estimating the loss potential for the insurance industry and other economic sectors

Links to other topics

The insurance sector has links to all other subject areas dealt with in this report:

Land ecosystems

Can provide protection against natural hazards (avalanches, floods etc.)

Agriculture

Crop failure due to hail, storm, flood, drought or frost

Water management

Loss due to water-related natural hazards

Health
Health insurance and life insurance, hospitals

Energy
Insurance of production losses

Tourism
Insurance of production losses

Infrastructure
Insurance of existing facilities

This chapter focuses on the possible impact of climate change on property insurance, with particular focus on the expected changes in natural hazards. As in many other sectors, the impact of changes in particular extreme events on potential losses, and not the changes in long-term averages, are in the foreground in the insurance sector. This relates to extremes in temperature and precipitation, as well as of wind and hail. Firstly, the operational mode and current performance of direct insurance and reinsurance companies are described, in particular for Switzerland. The impact of natural hazards on insurance is then discussed, based on possible changes in the frequency and intensity of these hazards.

2. How does insurance work?

The fundamental idea of insurance is to group together a large number of people who are at a similar risk, so that in the event of an incident, the people affected can be helped. Insurance is characterised by the following features: reciprocity, profitability, capital requirements, chance and predictability.[1]

An insurer uses the incoming premiums to pay the expected losses. Future losses need to be estimated correctly – with consideration of climate change – to make sure that insurance companies can operate profitably. If events that used to be out of the ordinary and random appear with regularity due to climate change, other loss mitigation measures will have to be taken. Insurance is only intended for cases in which the loss can neither be prevented nor reduced by taking measures.
If insurers want to reduce the financial consequences of catastrophic events or unpredictable fluctuations in claims experience, they can insure themselves.[2] This is called reinsurance. The insurance industry can compensate for large loss events over space, time and/or by including other classes of insurance.

Direct insurance

In table 1, the direct losses for the biggest storm, flood, and hail events in Switzerland are compiled for the different classes of insurance. For these events, damage to buildings and contents account for the largest proportion of the direct total loss. In the following section, we focus on these classes of insurance.
In Switzerland, there are two insurance systems for buildings and contents: The Public Insurance Companies for Buildings (KGV) and private insurance. Both systems insure against natural hazards unless they can be prevented by reasonable measures. Natural hazards are caused by natural phenomena (storm, hail, flood, snow load, avalanche, landslide and rock slide), which occur suddenly and unpredictably. Premiums for private insurance as well as for the KGV are approved by the state. A part of this premium is used for reinsurance (see below).

Cantonal Building Insurance (KGV)

In 19 cantons[3], the public KGV provides unlimited insurance against fire and natural hazards for all the buildings (80% of all buildings in Switzerland). The KGV are required by law within the framework of compulsory insurance and monopoly to cover damages caused by natural disasters. In the cantons of Waadt and Nidwalden, content is also insured by the KGV.

Table 1: The largest insured storm, flood and hail event in Switzerland, split according to property insurance classes (indexed for 2005). (Source: IRV, SVV, Swiss Hail Insurance)

in Mio. CHF	Lothar Storm 1999	Floods August 2005	Hail (Aargau/Zurich) 24.6.2002[a)]
Buildings	750	890	~125
Contents	140	820	?
Comprehensive auto	65	90	~80
Business interruption	20	200	?
Agriculture	2	10	8
Total	~1000	~2000	~250

a) On 8 July 2004, a hail event caused insured car damages of 100 million CHF. However, building damages were much lower.

Since the KGV usually only insure buildings, there is no compensation through other insurance classes, and because they act on a small scale, they lack geographical diversification. The KGV therefore buy additional coverage for out of the ordinary events at the Intercantonal Reinsurance (IRV), and together they offer each other mutual protection against extreme events in the inter-cantonal risk community. The IRV in turn buys reinsurance on the world market.

Private insurance

Private insurers insure buildings in the remaining cantons according to the Insurance Supervision Act (VAG).[4] Content is also covered by private insurance, except in Waadt and Nidwalden.

Private insurance companies also insure other objects, and, as a rule, operate nationwide or even internationally. Private insurers have also grouped themselves in a natural hazards pool in order to share the risk and pass it on to the international reinsurance market.

Reinsurance

Reinsurers operate worldwide and therefore form an even larger risk community. Thus risks are balanced worldwide and across different hazards. Reinsurers make it possible to insure even very expensive risks.

As a rule, reinsurance contracts, and in particular the premiums, are renegotiated annually. Essentially, there are two kinds of reinsurance contracts: In proportional contracts, both the incoming premiums and arising losses are shared. There is no loss limit. In non-proportional contracts, there is an upper loss limit. This is the most common kind of contract for natural hazards. Reinsurance can be purchased per event or for annual loss, that is the sum of all losses in a year. The KGV as well as private insurances have chosen annual loss as the reinsurance solution.

In addition to traditional coverage, reinsurance and financial institutions offer products that pass part of the risk on to the financial markets. Catastrophe bonds, so-called “cat bonds”, spread the risk across the financial markets. If the predefined event occurs, the invested capital is used to cover the damage, otherwise investors are paid out their invested capital plus interest. Currently, less than 10 billion USD are “insured” in cat bonds worldwide.[5] Cat bonds have the advantage of being independent of stock exchanges and money markets. Weather derivatives are also independent but are mainly used for the optimisation of profits. A payout is made based on the exceedance or shortfall of mean or at least frequently occurring climatologic values. Currently, the volume traded amounts to about 45 billion USD.[6] So far, cat bonds and weather derivatives only cover a small share of the risk in comparison to traditional reinsurance. The available capital on the financial markets is almost unlimited.

3. Claims experience

In Switzerland and worldwide, loss expenses and their variability have increased within the past 20 years. The share of climate change in the increase is largely unknown.

In the past decades, the losses caused by natural hazards have increased worldwide and also in Switzerland. This development is mainly caused by socio-economic changes:

1. Increase in insured assets as a whole and in particular in risk areas.

2. Increased vulnerability of buildings due to construction methods and use of vulnerable materials.

3. Increase in insurance penetration in Switzerland, which was and is already very high for buildings and contents.

4. Change in expectations of insurees.

How large an influence climate change has on the observed increase in losses has not yet been quantified.

The global increase in insured losses is represented in figure 1. It is clear that the losses from the largest natural hazards worldwide exceed those in Switzerland many times over. The year 2005 qualifies as the most expensive year for insurances so far; hurricane Katrina caused the largest ever insured loss of 56 billion CHF. This is considerably higher than the former record loss of 35 billion CHF caused by the hurricanes Ivan,

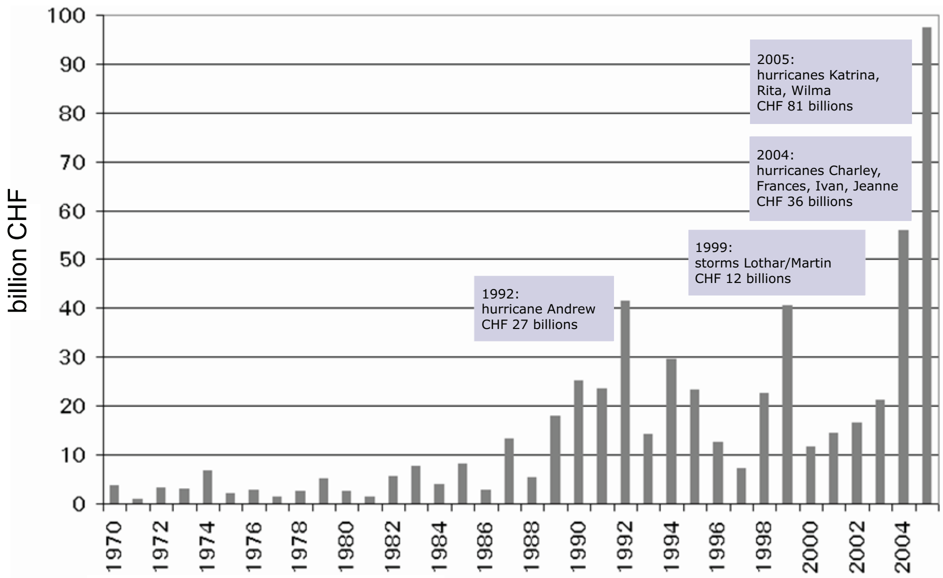

Figure 1: Global development of insured losses caused by natural catastrophes since 1970.

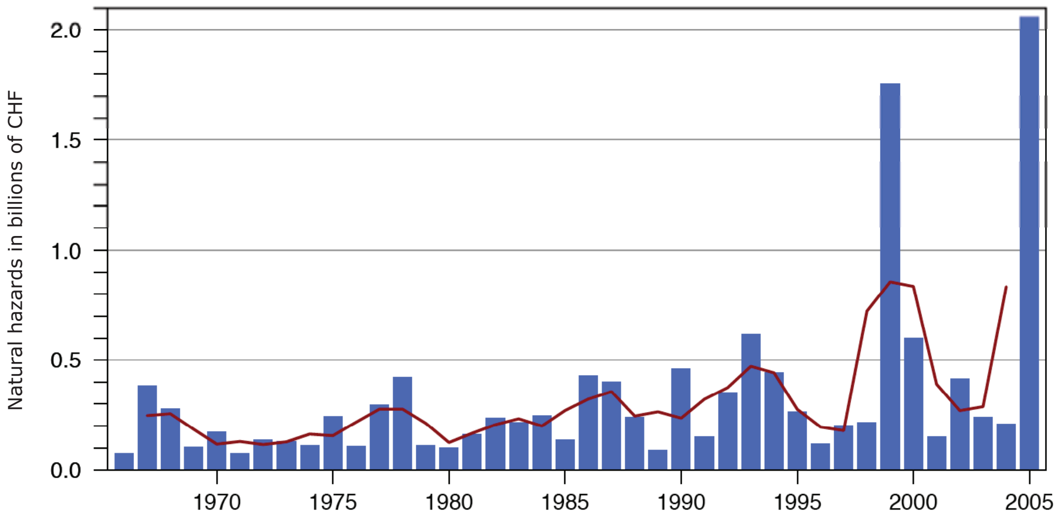

Figure 2: Insured losses in Switzerland (sum of losses of the KGV and private insurance, indexed for 2005). The line shows the 3-year mean. The increase in losses and variability is observable.
(Source: VKF loss statistics and SVV; for 2005, only provisional numbers are available)

Charley, Frances and Jeanne in the year 2004. The largest insured loss due to a winter storm amounted to 5.9 million CHF (all of Europe) and was caused by Vivian in 1990. The largest insured losses due to flood so far (4.5 billion CHF) were caused by the flooding of the Danube and the Elbe in 2002.
In Switzerland, an increase in insured losses due to natural hazards can also be observed (fig. 2). The red line shows the 3-year mean, which flattens the outliers. The general increase as well as the increase in variability are observable. The two most expensive years were 1999 and 2005. The year 2005, with losses of more than 2 billion CHF, was the most expensive year for insurances so far. By far the largest part was caused by the floods in August, which has been the most expensive single event up to now. Insured losses in the year 1999 – caused by the avalanche winter, floods in May, a hail event in July and the winter storm Lothar – amount to about 1.8 billion CHF.

Loss potential

Much larger loss events are conceivable than the largest natural hazards which the insurance industry has up to now had to deal with. In the insurance industry, the term loss potential refers to the estimated insured loss of very rare, but possible, events. In the insurance industry, this is called the Possible Maximum Loss (PML). In table 2, the largest loss potentials are compiled for Switzerland, Europe and the world. Since these numbers are estimates, the loss potentials in the table only give orders of magnitude. For comparison, the largest loss event that has occurred to date is presented. The table indicates that in Switzerland, an insured loss of 3 billion CHF for each hazard must be anticipated every 200–300 years. This is the statistical mean. It is also possible for such an event to occur twice, one straight after the other.
Table 2 shows that the insurance industry within Switzerland but also worldwide has to be prepared for enormous potentials that exceed the largest historic events many times over. It is therefore of great interest whether and how the potentials could change due to climate change. In addition, estimates are usually based on experiences from the past and are therefore only useful to a limited extent for the medium-term future.

Table 2: For a 200- to 300-year event, the rough loss potential for storm, hail and flood in Switzerland, the EU and worldwide is given.
(IRV, Swiss Re, PartnerRe, and other insurance contacts)

	Switzerland		**EU**		**Welt**	
in billion CHF	Potential[a)]	Largest loss	Potential[b)]	Largest loss	Potential[b)]	Largest loss
Storm	~3	1	50[c)]	5.9[d)]	150[e)]	56[f)]
Flood	>3	2	15[g)]	4.5[h)]	n/a	n/a
Hail	<2[i)]	0.25	4.5[j)]	1[k)]	n/a	n/a

a) The numbers given for Switzerland are based on a study of the Intercantonal Union of Reinsurance and relate to building losses of the 19 KGV, with a return period of about 250 years (Source GB-IRV 2003). The losses of private insurers were roughly estimated.
b) The numbers given for Europe and worldwide are based on a return period of 200 years. (Source: Swiss Re 2006)
c) Winter storms
d) Winter storm Vivian 1990
e) Tropical storms including storm surge
f) Tropical storm Katrina 2005
g) This concerns insurable potential, that is, under the assumption of flood insurance penetration, like for fire.
h) Floods 2002
i) A large part of Switzerland is located in the zone most at risk for hail events, therefore the loss potential is high in comparison to all of Europe.
j) "Hailstorms in Europe – a new look at a familiar risk", Swiss Re 2005
k) Hail, Munich 1984

4. Future perspectives

The following section gives an overview of (selected) future changes in risks. Possible changes in winter storm, flood and hail risk are described and the consequences for insured losses are discussed. The Background chapter contains a summary of the changes in extreme events up to 2050.
The part of climate and societal changes in the development of losses is today not yet sufficiently taken into consideration for risk assessment and risk management. There is particular need for research into the consideration of future losses due to extreme events.

Although the results of scientific studies are becoming increasingly consistent and comprehensive, there are still uncertainties with regard to the impact of climate change on the development of losses (figs. 1 and 2). Thus, for instance, it is unknown to what extent climate change has contributed to the increase in losses within the past 30 years. The separation of different socio-economic and climatologic influences turns out to be particularly difficult because the cause and effect chain from natural hazard to damage is a complex process that is difficult to model (see Water management chapter).

Winter storms

Winter storms represent the largest loss potential for Europe and the second largest for Switzerland (see table 2). In order to analyse the impact of climate change on winter storms in Europe, and in particular to quantify the consequences on insured losses, scientific models are increasingly coupled with loss models used by the insurance industry.

In a study by Swiss Re and ETH Zurich[7], several climate models were coupled with an insurance loss model and future storm damage by winter storms was examined. It was shown that in the long term, climate change could lead to more frequent and more intense winter storms and therefore also to higher losses. By the end of the 21st century (2071–2100), the losses Europe-wide could increase by 20 to 70%[8] compared to the reference period (1961–1990) (fig. 3). In Switzerland, an average increase in losses due to winter storms of about 20% (0–50%, depending on the climate model) is expected. There are no corresponding model calculations for the year 2050. It can be assumed, however, that already by then, an increase in storm losses will be observed, even if to a lesser extent. It is obvious from the model calculations that as a result of climate change, the rare extreme events with serious consequences, such as the winter storms Lothar or Vivian, will affect the above-mentioned increase more strongly than less intense events: For 100-year events, the increase will amount to about 100% Europe-wide, for 10-year events to about 20%.

Floods

Calculations using regional climate models show that as a result of climate change, the return period of 5-day precipitation amounts (characteristic of long-lasting, intense precipitation) could halve in Central Europe in the future climate (2071–2100).[9] A 100-year event would become a 50- to 100-year event, a 20-year event would become a 10- to 20-year event. This change would have far-reaching consequences for flood risk and the resulting losses. If, for instance, the risk of floods of the extent of the flood in August 2005 doubled in Switzerland, risk assessment and risk management would have to be adapted. Further consequences affect the planning and dimensioning of protective measures (see Water management chapter). Similar to storms and hail, estimates of flood risk need to take into consideration societal changes (where and how is built and utilised).

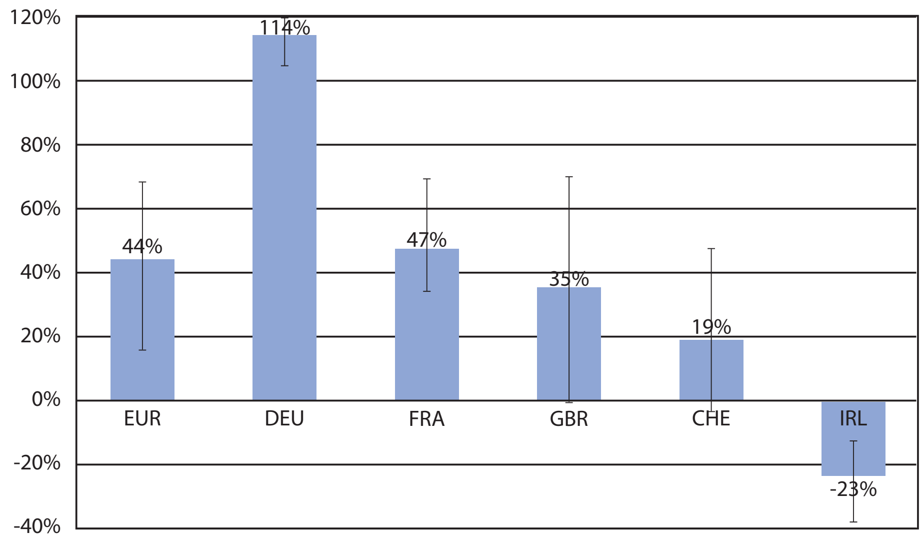

Figure 3: Mean increase in annual losses in Europe (EUR), Germany (DEU), France (FRA), Great Britain (GBR), Switzerland (CHE) and Ireland (IRL) for the time period 2071–2100 in comparison to the reference period 1961–1990. The blue bar indicates the mean value of the climate models, the error bar shows the spread of the models.
(Source: P. Heck, D. Bresch and S. Tröber. The effects of climate change: Storm damage in Europe on the rise. Swiss Re Focus report no. 1503160_06_en, 2006)

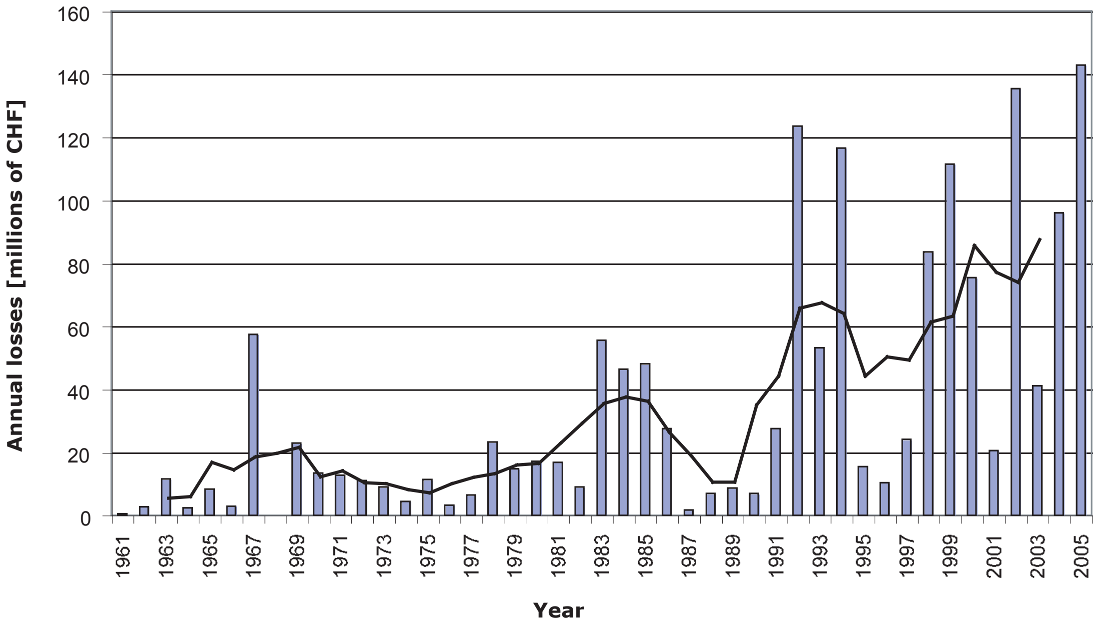

Figure 4: Hail losses of the Public Insurance Companies for Buildings; indexed for the Zurich building-cost index and inflation of 1.5%; includes only buildings, the data for 1968 is missing and for 2005 provisional; black line: 5-year running mean. (Source: VKF loss statistics)

Hail

Large parts of Switzerland are in an area of high hail risk in comparison to large parts of Europe. Accordingly, the loss potential is big. Since 1940, the large-scale weather patterns that are responsible for extreme hail events in Switzerland have increased considerably. If the frequency of these weather patterns also increases in the future, more frequent hail events are to be anticipated.[10] Since hail events are very local events, it is difficult to simulate them with climate models and to make forecasts about future changes.

Losses due to hail events have also increased in the past. In the past 15 years, the Public Insurance Companies for Buildings have recorded losses about four times higher than in the 60s and 70s (fig. 4).

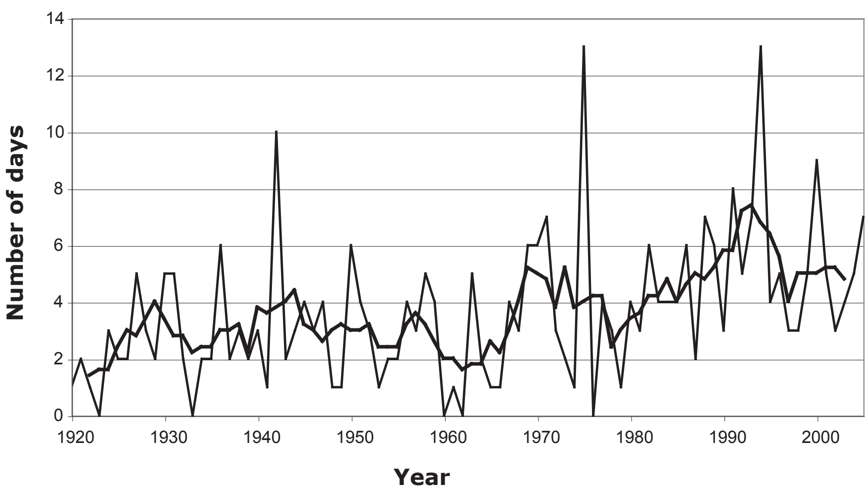

Figure 5: Time series of the number of hail days with 100 or more affected municipalities from 1920–2005. The increasing trend of intense hail days between 1980 and 1994 is clearly visible. (Source: Hans-Heinrich Schiesser)

There are different reasons for this development. Firstly, the number of heavy hailstorms has increased (fig. 5). However, the increase in events is less pronounced than the increase in losses. Secondly, societal changes contribute to the increase in losses. This includes the use of unsuitable materials for hail (e.g. slat blinds and metal cladding) and the increased expectations of insurees. Finally, in the case of small-scale hail storms, the extent of damage strongly depends on coincidence. It is possible that in recent years, areas with higher asset values have been increasingly affected due to coincidence. These three causes act in combination on the development of losses: If hail storms increase as a result of climate change, the probability that areas with high asset values and delicate materials will be affected will also increase.

Conclusion

It is necessary to better quantify the part of climate and societal changes in the development of losses and to include them in risk assessment and risk management. It is important to consider uncertain predictions as well, particularly in regard to decisions with long-term effects. In the area of property insurance, the changes in extreme events will play the most important role. Studies in this topic area will therefore be necessary as a basis for decision-making and should correspondingly be of high importance in science.

5. Impact on insurance and measures taken by insurers

Climate change and the associated change in intensity and frequency of natural hazards have manifold effects on the insurance industry. A part of these effects can be financially covered by measures taken by the insurance industry itself, others require measures at the social and political level.

Impact on insurance

As mentioned in section 2, insurance is based on reciprocity, profitability, capital requirements, chance and predictability. These characteristics are influenced by climate change in various ways:

Reciprocity

In the future, it will be less acceptable to charge all insurees in affected and less affected areas uniform premiums to finance the losses. Thus, solidarity will be questioned.

Profitability

Incoming premiums will also have to cover the losses in the future. If large loss events become more frequent or more expensive, the premiums and insurance conditions will have to be adapted accordingly in order for the insurance industry to continue to operate profitably.

Capital requirements

If, in addition to the intensity of loss events, the variability also changes, insurance companies will need to have more capital available to cover the losses or buy higher reinsurance cover. Reinsurance cover can be adapted at short notice, whereas an increase in capital usually takes time and should occur before higher losses reduce the capital.

Chance

Climate change affects the frequency of events. Extreme events that are out of the ordinary and rare today, could occur regularly due to climate change and become the norm (fig. 6). Regular, predictable losses are contradictory to the basic principles of insurance. For these, preventive measures need to be taken.

Predictability

The predictability of a risk is simpler the larger the amount of data, the longer the available data series and the smaller the variability of the data. In order to include climate change in risk analysis, predictions about the expected changes in intensity and frequency of extreme events, and an estimate of their uncertainty are required.

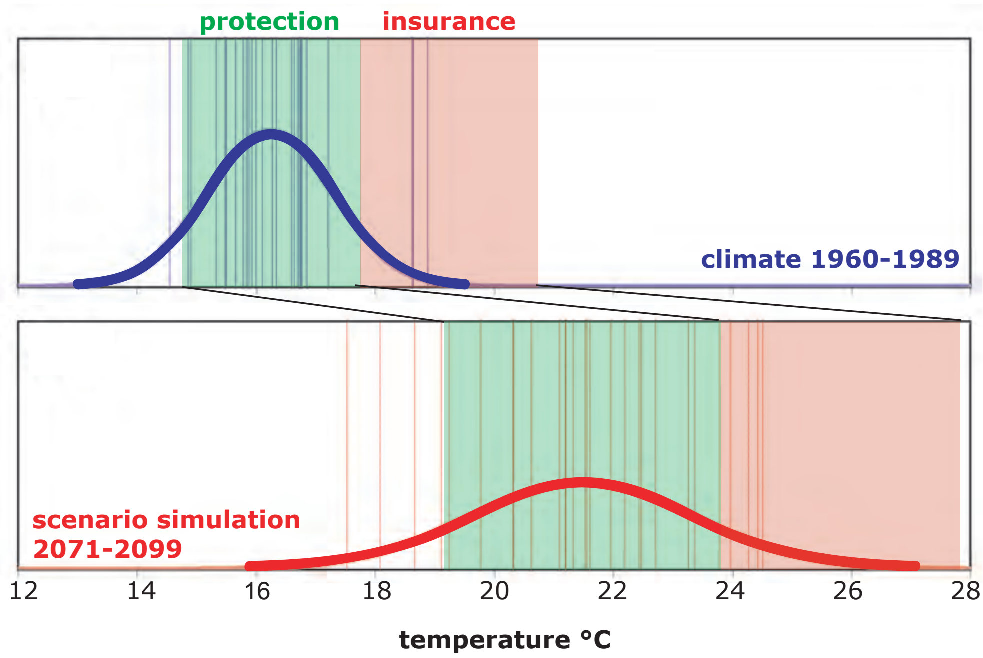

Figure 6: Climate change will change the probability of occurrence and the intensity of events (example of summer temperatures, transferable to natural hazards).[11] Insurances cover the losses caused by out of the ordinary, rare, extreme events (red area in the upper figure). If such events become the norm as a result of climate change, other measures will have to be taken to avoid and recover losses (green area in the lower figure). At the same time, the intensity of the extreme events that are intended to be covered by insurance increases (red area in the lower figure).

Measures taken by insurance companies

Insurance companies have several possibilities to react to the above-mentioned effects. In this regard, it is important for the entire insurance industry to include scientific findings about the impact of climate change in risk models.

Direct insurance

Increase in premiums

If the intensity and frequency of loss events increase, insurance companies will have to raise premiums in the long term, in order to continue to be able to pay the arising losses. Premiums will also need to be raised in the event of an increase in reinsurance cover and/or capital.

Adaptation of insurance conditions

Insurance conditions can be adapted. This can be achieved by a higher deductible, by exclusion, or by a cover limit. These adaptations could lead to losses being only paid in part by the insurance. With a deductible, the insurance pays for losses above a certain amount. This may encourage house owners to protect and maintain their houses in such a way that no predictable or avoidable losses arise. Insurance may exclude, for instance, delicate building materials that according to present knowledge may not resist predictable natural hazards. A cover limit caps the claim to be paid by the insurance.

Risk premiums

In Switzerland, risk premiums for single properties only make limited sense. The premium for all natural hazards (storm, hail, flood, landslide, snow load, avalanche, rockfall and rock slide) amounts to less than 50 cents per 1000 CHF insured. For a single-family house worth 500,000 CHF, the premium amounts to less than 250 CHF per year. Only a massive increase in this premium would cause a stubborn owner to invest money into loss reducing measures. Higher deductibles are more effective.

Reinsurance

In the case of reinsurance, an increase in the frequency and intensity of large loss events will lead to an increase in reinsurance premiums. Reinsurance companies have to increase their capital in order to continue to be able to pay the increasing claims. Furthermore, reinsurance companies can spread their risk more broadly by buying cover for extreme events from other reinsurers (called retrocession) or via cat bonds on the financial market. It is also conceivable that other instruments for risk transfer will be developed.

Measures by society

Societal adaptations are also required in order to cope with the changes in intensity and frequency of extreme events as a consequence of climate change.

Exclusions, cover limits and insufficient reinsurance cover (or insufficient capital) can lead to gaps in cover that have to be paid for by society or the state. An increase in premiums can be problematic if a large proportion of society can no longer pay the premiums. In terms of sustainability, the goal must therefore be to reduce the effects of natural hazards through societal and political parameters.

On the political level, parameters will need to be adapted – also in the interest of the state – to enable the insurance industry to continue to operate profitably, even if, for instance, higher capital reserves are required to manage higher claims.

At the same time, measures need to be taken to reduce the extent of losses. Spatial planning can influence where building is allowed and where not. In spatial planning, not only the present but the future geographical extent of natural hazards will need to be considered (see Urban Switzerland chapter).

Construction standards and building laws can influence how and with what materials building is carried out (see Buildings and infrastructure chapter, section 2). It is also necessary to consider future changes here. Planners and builders should be encouraged to plan and to build with the future in mind. Buildings exposed to the weather and at high risk should be built to resists today's bad weather as well as that of the future. Events that are out of the ordinary today, could become the norm by 2050 and should therefore be considered in today's planning.

Insurance companies can support the different adaptations. On the political level, they can advocate creating suitable parameters to cope with the future challenges. Furthermore, insurance companies can promote and call for hazard maps and their implementation, develop instructions and brochures on appropriate building for natural hazards, and provide lists of suitable building materials. By means of exceptions, conditions and exclusions, insurance companies can enhance implementation, however, often only after the damage event.

From an economic perspective, efforts to reduce greenhouse gas emissions are also effective measures for reducing the vulnerability to change. This is particularly valid if emission reductions also protect against climate change (see boxes on emissions trading and climate policy, and on sustainable investments for enhancing energy efficiency.)

Emissions trading and climate policy

The flexibility mechanisms of the Kyoto protocol (Clean Development Mechanism (CDM), Joint Implementation (JI), Emissions Trading) aim at reducing greenhouse gas emissions as cost-effectively as possible. Measures should be taken where they can be realised the most cheaply. The flexibility mechanisms are the only instruments with which to include regions without emission reduction obligations in international climate protection efforts. In addition, emissions trading connects greenhouse gas emissions and capital markets.

By means of emissions trading, a country may participate in the climate protection measures of other countries. A distinction is made between emission rights that are allocated to a country or a company within the framework of the Kyoto protocol or within a closed trading system, and emission rights that are generated by a climate protection project in another industrialised country (JI) or a developing country (CDM). In 2005, the trade volume of allocated and generated emission rights was about the same.

Certificates are traded in different trading systems that are not linked. The most important is the European Union Emission Trading Scheme (EU-ETS). Other trading systems exist, for instance, in the non-Kyoto countries Australia and the USA. The World Bank is the central institution for transactions of emission allowances that are generated by CDM-projects in developing countries. The development of prices varies considerably for the different markets.

The development of emission rights trading depends on the future development of international climate policy. The following conditions are important for the success of emissions trading:

1. Reduction measures need to pay off. The price for CO_2 should be high enough so that a change to energy supplies with a more favourable energy/emission-relationship, as for instance from oil to gas, is worthwhile.
2. Binding, long-term reduction targets are required so that trading of greenhouse gas certificates has long-term prospects.
3. The different trading systems should be linked to each other and be organised as globally as possible, so that the market can develop full efficiency. A ton of avoided CO_2 will always have the same value for the climate system, irrespective of location and regional reduction target.

Prof. Georg Müller Fürstenberger

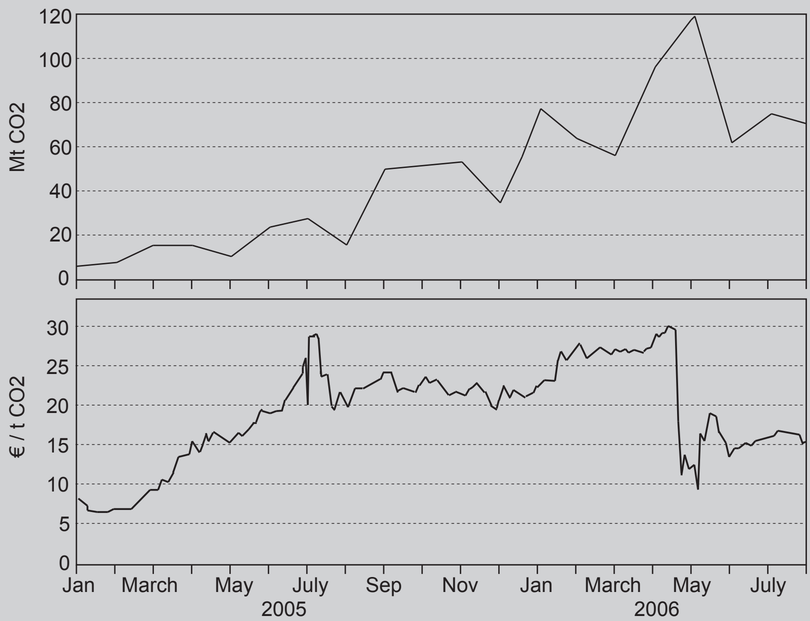

Figure 7: Entire trade volume and price development of emission rights in the European Union Emission Trading Scheme EU-ETS. Since the beginning of EU-ETS in January 2005, the monthly trade volume has risen from 10 million t CO_2 to more than 60 million t CO_2. The certificate prices still fluctuate strongly.

Sustainable investments for enhancing energy efficiency

Companies that deal considerately with humans and the environment generate sustainable profits for their shareholders – this reflection is the basis for sustainable financial investments. However, sustainability funds (Sustainable Responsible Investment, SRI-Fonds) still play a minor role in Switzerland. Of the 500 billion CHF that were invested into basic funds in Switzerland in 2005, the share of so-called SRI-funds amounted to just 1%, in spite of the fact that SRI-funds are on average at least as successful as traditional funds.

Changes mean a challenge to the economy. It must adapt to the changed conditions as quickly and as well as possible. This is the case with climate change, which alters the political and economic parameters. Examples for this are the public funding of renewable energy and energy efficiency, or emissions trading. Investment consultants invest in firms that are best at adapting to changed conditions and take advantage of the chances offered by novel products.

Technologies for enhancing energy efficiency result in a reduction of emissions and energy costs. There are numerous examples of firms that have saved a lot of money by investing in energy efficiency: The BT Group (British Telecom) saved 214 billion USD between 1991 and 2004, DuPont has been able to save about 2 billion USD since 1990. Despite this, risk capital is hardly ever used to promote the corresponding technologies.

Today, basic funds that invest in technologies for enhancing energy efficiency, usually choose investments according to relative criteria. As a rule, it suffices that firms and technologies demonstrate an above-average energy efficiency. The question of whether they will meet a long-term efficiency target does not play a role here. However, in order that technologies for enhancing energy efficiency contribute to the long-term climate protection goal, their selection must depend on long-term climate protection and energy efficiency targets:

- In the case of climate protection, Western industrial countries should reduce their greenhouse gas emissions by 60–80% by 2050. This represents an annual reduction of 2–3.5%.
- Under the assumption that an industrial sector increases by X%, its efficiency should be increased by (2+X) to (3.5+X)% per year.

From today's perspective, it is clear that only new technologies will be able to fulfil these requirements.

Dr. Gerhard Wagner (UBS) and
Simone Schärer (SAM)

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Synthesis

1. Introduction

How will global climate change affect Switzerland in the year 2050? Although nobody knows the future, scientifically based estimates of probable developments allow us to consider smart adaptation strategies early and make anticipatory decisions. After having concretely described and discussed the expected changes in individual sectors in the previous chapters, this chapter will consolidate these reflections and draw conclusions. We comment on the following questions from the perspective of five topics – Creeping changes, extreme events, water, space, and changes for humans:

- What changes await us and why are they important?
- Which adaptations are already observable? Are they advisable against the background of the overall problem or do they represent only superficial or even counterproductive pseudo-solutions?
- What does this mean for a comprehensive and responsible climate strategy?

As humans we are integrated at one and the same time into the material and energy-related cause and effect relationships of the material world and into those of a societal nature. This integration expresses itself in many ways. Thus, the development of techniques for the exploitation of fossil energy sources has set in motion not only a long-term change in economic and social but also in climate and ecological systems – changes which in turn have repercussions for us humans and demand from us adaptation and problem solving.

We know that the most important contribution to solving the problem of climate change consists of drastically reducing the global emission of greenhouse gases. This solution, which approaches the problem from its cause, is called mitigation. There is no alternative to this! The nature of the climate system is such that it demands drastic emission reductions, which will be difficult for us to achieve due to their radical nature. Thus, for the time being, it is still uncertain, when and how we will succeed in taking the necessary large steps in reduction. It is certain, however, that even in the case of quick successes in mitigation, climate change will proceed in the coming decades, due to the increase in greenhouse gas concentrations in the atmosphere (delayed consequences) caused by human activity. Therefore, we need to prepare simultaneously for local and regional restrictions due to climate change. An ideal adaptation strategy includes the greatest possible minimisation of the expected damage and at the same time the maximum utilisation of the resulting opportunities. This damage-limiting strategy is called adaptation. This report focuses on the impact of climate change around 2050 and the question of what kinds of adaptation Switzerland has to achieve in addition to the urgently needed efforts in the area of mitigation.

The statements made in this report in relation to the expected mean changes in the climate system, as well as their impact on society, the economy and ecosystems do not sound particularly dramatic, in part because most of them are likely to be within the range of natural variability in our latitudes around 2050. In most cases, society can react to them with appropriate adaptation measures. This circumstance must not obscure the fact that our actions today will determine the future of the climate, and the massive economic and social costs associated with it after 2050. Between 2050 and 2100, the effects of climate change will be extremely noticeable and cause great damage in Switzerland, as elsewhere. Then the consequences for Switzerland will be far more drastic than presented in this report. That is why immediate action in the areas of mitigation and adaptation is now becoming urgent.

2. Creeping changes

The scenarios for 2050, on which this report is based, mainly focus on mean values. In this case it is expected that winter temperatures will increase by about 1.8 °C and summer temperatures by about 2.7 °C compared to 1990. The related average change in climate caused by these rises will affect various systems, e.g. glaciers, permafrost, the hydrological cycle, vegetation, animals, buildings and human well-being.

Precipitation will decrease in summer and tend to slightly increase in winter. As a result, annual mean precipitation will slightly decrease compared to today. These changes go hand in hand with changes in atmospheric circulation. Thus it is expected that in summer, the Azores high will extend more often over the continent, which will tend to lead to more heat waves and dry spells. In winter, a northern shift of the Westerlies is predicted, with low-pressure systems probably having lower central pressure. This will possibly result in less but stronger westerly storm occurrences. Even just the average warming caused by this and the change in mean precipitation will have grave consequences for various systems, e.g. glaciers, permafrost, the hydrological cycle and vegetation. Many changes will proceed over long periods of time. In some cases, nature and humans will have sufficient possibilities to adapt to the changed conditions. For instance, some species will be able to migrate to regions where the climatic conditions are more suitable to their requirements, if no major obstacles get in the way and if there is enough time. Agriculture will be able to adapt to the changed conditions by adapting its selection of varieties, species and management methods. Other changes, however, will leave irreversible damage behind, although they too will proceed slowly. For instance, many of the smaller glaciers will have disappeared by mid-century, which will change our mountain landscape permanently. Species that cannot migrate to climatically favourable regions will also disappear entirely. In their place, foreign species will immigrate, which as a result of the expected time lag will also lead to permanent long-term changes in the landscape. Skiing regions at lower elevations will not be able to be run economically due to the absence of snow. Some changes, such as a milder climate, will be perceived as positive and offer opportunities for humans. For instance in our latitudes, agricultural yield increases will be possible with a more moderate climate. In various regions, particularly in the mountains, summer tourism will profit from a warmer and drier climate (catchword: "summer retreat"). In winter, the demand for heating energy will decrease considerably.

Whether or not the local impact of climate change to 2050 will have a negative effect on humans and ecosystems, that is, how vulnerable they are, depends on three factors: Firstly, to what extent a system is exposed to climate change (e.g. a heat wave affects the people in the lowlands far more than those in the mountains); secondly, how susceptible a system is to the effect in question (e.g. old people's health reacts more sensitively to out of the ordinary hot spells than young people's), and finally; on how well a system can adapt to changed conditions (thus hot spells will affect even susceptible people less if they can retreat into cool rooms). As a rich, politically stable country with a high level of education and great technical, financial and institutional opportunities, Switzerland basically possesses a great capacity for adaptation in the face of climate change. But the necessary adaptation will neither take place nor be financed automatically, and whether it can reasonably be expected or not will have to be discussed on a case-by-case basis. What is certain is that the sooner we recognise our weak points and decide on smart adaptation strategies, the lower the vulnerability of our country will be.

We are used to swift, conspicuous and at times drastic political, economic and social changes, and we have numerous societal adaptation mechanisms at our disposal. In comparison to this, many effects of climate change will start imperceptibly, often with a time delay and occurring in the background, like, for instance, the gradual change of the species composition of a forest, the warming of rivers or the earlier occurrence of the last late frost in spring. However, they will challenge us in a unique way. This is because our patterns of economic utilisation of ecosystems and of space, our architecture and household technology, our daily and seasonal organisation of working hours and leisure time, etc., which we have developed in the past decades or centuries, are based on the assumption of a constant climate within human time horizons and with more or less well-known fluctuation patterns and predictable frequencies of extreme events. With climate change we are faced with changes in these background conditions of our economy and our social life that are not precisely predictable in every detail. Therefore, new and very flexible adaptation mechanisms will be required.

Spontaneous, superficial adaptations will not suffice or will be counterproductive. For instance, we will possibly tend to adapt to higher temperatures and more frequent hot spells by increasingly installing individual air conditioners in existing buildings. This strategy will solve the problem superficially (humans will bear the heat better and remain efficient) but will drive climate change – to the extent that the additional electricity demand is covered by, amongst others, fossil energy sources (EU electricity mix) – and therefore does not represent a sustainable form of adaptation. A sensible long-term strategy will include a consistent push towards modernising current building stock in the direction of the passive house, which offers a comfortable room climate in hot and cold weather, with minimal external energy input, together with the daytime reorganisation of working hours. Although such adaptations are more demanding and require more persistence, they are to be preferred because they simultaneously contribute to the preventive avoidance of major changes in climate.

3. Extreme events

Hot and dry summers as experienced in the year 2003, could already become distinctly more frequent and even more extreme by 2050. It is foreseeable that there will be more precipitation in winter and less in summer, with an expected higher variability and an increase in precipitation intensity. The damage risk for infrastructure such as transport networks, tourist facilities and communities will increase.

Adaptation to mean warming levels and the change in mean precipitation will by their very nature take place relatively slowly. Adaptation to changes in extreme events and the associated natural hazards, however, mostly have to be carried out swiftly and are, in addition, less easy to estimate. As already shown in an earlier report by the OcCC on extreme events and climate change1, it is far more difficult from a scientific perspective to make reliable and concrete statements about the changes in extreme events. Nevertheless, the discussions in expert committees and at workshops have shown that the greatest impact on the areas studied here will come from two types of extreme events: Heat in combination with drought, and heavy precipitation in combination with higher temperatures. There will also be the associated natural events such as landslides, floods, etc.

Heat and drought

Hot and dry summers as experienced in the year 2003, could already become distinctly more frequent and even more extreme by 2050 (see Background chapter). Besides a considerable warming, it is also expected that there will be increasing variability in the summer climate, with a substantial increase in extreme heat waves. Agriculture, natural ecosystems on land and water, Rhine shipping and energy production will be seriously affected (see section 4). Measures to cope with the conflicts arising from competition associated with water shortage will have to be developed.

The effects are particularly noticeable for human health, mainly that of elderly people, those in care and sick people but also for the productivity of the working population. Education about measures to be taken at home, in the organisation of daily life and the support of long-term care patients is an important and simple adaptation measure. Adaptation of construction methods for apartments and office buildings is urgent but will require correspondingly long lead times (see section 5). Adaptation measures that consume additional electricity are seen as inappropriate in any case, since it can be assumed that the European electricity market will be under particularly high pressure in such summers.

Hydroelectric power production in run-of-river power stations will be greatly reduced, since on the one hand, there will be droughts and on the other, there will be little meltwater available in summer from the few glaciers and the scarce snow reserves. Thermal power plants that rely on river-water cooling, such as our nuclear power plants, could produce electricity only to a limited extent, since firstly, there will be too little cooling water available, and secondly, the heated river water should not be artificially heated even more. In addition, with stable high-pressure weather conditions over Europe, wind power will also only be available to a very limited extent.

Tourism in the mountain regions could profit from a revival of people seeking a summer retreat. Many heat-afflicted people from the towns will spend the summer at the lakeside or in the cooler mountain air. Heat and drought will mean an additionally increased probability of forest fires, not only on the southern side of the Alps and in the Valais but as a new phenomenon also on the northern side.

More intensive precipitation and increased temperatures

Precipitation will change all over Switzerland. According to the model calculations available, there will be more precipitation in winter and less in summer. This means that the seasonal variations will become smaller. The average annual precipitation may well decrease by about 5% (i.e. by 75 mm in the north and 120 mm in the south). The variations from year to year or month to month could continue to be considerable and sometimes even intensify. This will mean increasingly drier or wetter periods. Precipitation intensity may well increase in winter and probably also in summer.

As a consequence of this, the frequency of heavy precipitation will increase, particularly in the winter half-year. For summer, the current predictions are less clear. The model results show that precipitation as heavy as it occurs only every 8 to 20 years nowadays, will occur every 5 years on average by the end of the century. However, more intense precipitation does not automatically mean dangerous river levels or even flooding. In the midlands and the Jura as well as the foothills of the Alps below about 1500 m a.s.l., where already today there is danger of flooding in winter/spring, the danger of floods could increase. This is also particularly true for the neighbours further down the Rhine. Associated with this, the rise of the mean snow line caused by warming will also affect the discharge regimes of rivers and their potential for floods.

Natural hazards: Rockfalls, landslides and mudflows

The retreating glaciers leave new large and loose masses of debris in their wake. Additionally, the ground gets warmer: In particular, permafrost will partly thaw and result in landslides and smaller or also larger rockfalls. The new loose debris will accumulate in ditches and riverbeds and, in the case of floods that are triggered by more intensive precipitation falling as rain up to higher elevations, may be carried away and reach valleys and inhabited areas as mudflows. Erosion, bed-load discharge and sediment deposition are very often responsible for the serious damage caused by floods. The potential for such events will increase considerably, however only in mountain areas.

Wet soils on steep slopes can come down as landslides in the case of heavier precipitation. Since in winter in the future, there will be more, possibly heavier precipitation and at higher altitudes, more of the steeper slopes will be affected and therefore more of this type of landslide will occur. This will mainly affect the foothills of the Alps. Altogether, there will therefore be an increased risk of damage to infrastructure such as transport networks and tourism facilities in mountain areas. In addition, human health may be endangered, be it by injury and death, or also by the psychological effects of the increased risk or loss of property and belongings or of closely related people.

Natural ecosystems such as protection forests can temporarily lose their protective capacity due to this greater volatility. However, in general this will usually not represent a fundamental risk for the ecosystems themselves. However, because of the reduced functionality of the ecosystems, it will affect to a much greater extent the security of human settlements and transport networks.

In particular in the climatic border zones in the mountains, with thawing permafrost or at dry sites, chain reactions including pest attacks can weaken ecosystems. A variety of combinations of species suitable for the particular location can increase the resistance and therefore also the security of human living space in the mountains.

Adaptation measures for the protection of people include comprehensive prevention in adapting land use by avoiding dangerous locations, biological measures such as the management of protection forests and protective measures in the construction industry. Besides prevention, organisational measures before and immediately after the event are also of vital importance. These comprise the introduction and maintenance of warning and alarm systems, and well functioning evacuation and emergency assistance.

4. Water cycle and water resources

In winter, there will more frequently be rain instead of snow up to medium elevations. This will affect winter tourism. In addition, about 75% of the water stored in glaciers will be lost. It can be expected that competition for water will increase during dry periods. The expected changes in discharge will increase the potential for flooding, particularly in winter and spring.

The effects of climate change on the water cycle and water management by 2050 are discussed in the Background and Water Management chapters. The most important changes are summarised here once again:

In winter, there will more frequently be rain instead of snow up to medium elevations and the snow cover will decrease. However, at high elevations (above about 2000 m), where it usually snows in the winter half-year, the snow cover will become thicker due to the expected increase in precipitation.

Three quarters of the water resources that are bound up for the long term in glaciers, will probably have disappeared already as early as 2050. This is about 40 cubic kilometres of water.

Evaporation – the loss term in the water cycle – will continue to increase with the rise in temperature. In summer, more frequent drought periods will prevent water supplies from increasing and, for instance, in the case of glaciers even contribute to an accelerated ice loss. Thus, altogether, the available water resources in Switzerland will decrease.

In winter and spring, there will be more water in the rivers and streams, particularly at medium and lower elevations. More intense heavy precipitation may lead to greater high water levels, above all in the midlands and the Jura, as well as in the foothills of the Alps below about 1500 m a.s.l. The groundwater levels will be high everywhere. In summer and autumn, less water will flow on average than today. Primarily during more frequent drought periods, the rivers in the midlands and in the Jura but partly also in the mountains will hold significantly less water. In addition, smaller streams may almost or entirely dry up. In particular in the lower reaches of larger rivers, there will be lower water levels in late summer and autumn. With the scarcity of water, the groundwater levels will sink. This will have a critical effect, particularly on smaller aquifers. The trend in flooding is uncertain. In the case of a combination of unfavourable weather conditions, there may be massive flooding also in summer.

Consequences for various water users

The experiences gained in the heat wave summer of 2003 have clearly shown the sensitivity of the Swiss water usage to dry summers.2,3 The changes in the water cycle will affect the different areas in the following ways:

In the energy sector, there will be less water available for hydroelectric power production; the losses may amount on average to about 7% of today's output. However, the supply of water will be more evenly distributed over the course of the year. During periods of drought, there will be less and only relatively warm water available for the (continuous flow) cooling of thermal power plants (e.g. nuclear power plants) or for industry. Losses in electricity production are therefore to be expected. Adaptation measures are difficult. The lost electricity production from hydropower must not be compensated for by fossil energy, since otherwise an undesirable feedback mechanism would be set in motion, which would undermine the mitigation efforts.

In agriculture, the potential annual production of meadows will increase with moderate climate change, due to the longer vegetation period. However, there will increasingly be critical groundwater levels and summer droughts in Switzerland as well as elsewhere. Irrigation would then become necessary at many locations. In view of the limited water availability in drought years, the cultivation of less water-demanding plant varieties will be preferable to irrigation.

Of the natural ecosystems, the low moors in particular will come under pressure and be reduced in area through lack of water. This may well produce a decline in the number of species. Other wetlands will be less affected. Due to the retreat of the glaciers and snowfields, new areas will emerge that will slowly be settled. Overall the flora and fauna will approach that of the Mediterranean. In the forest, productivity will begin to fall due to water shortage. With increasing frequency and over longer periods, the forest ecosystem, which formerly served as a carbon sink, will become a carbon source. As this occurs, less carbon will be stored in the soil in the long term and the affected soils will temporarily break down considerable amounts of organic substances, which will also affect mitigation measures. Countermeasures would be an expansion of forest areas, as well as a more comprehensive targeted sink management of current forest stands.

Rhine shipping will from time to time in summer and autumn be massively constrained in its transport capacity. This will result in an undesirable switch to more expensive and more energy-intensive means of transportation, which, again, is contradictory to mitigation measures in the area of transportation.

Altogether, above all during drought periods, there will be new competition for water in the small and medium rivers of the midlands: Agriculture would like to pump irrigation water; the demand for cooling water will increase; the exfiltration rate of rivers and streams will increase due to sinking groundwater levels; the supply of drinking water will take more water from the total system due to the increased demand for drinking and irrigation water; and ecosystems like rivers and streams will need sufficient and not overheated water in order to survive. In addition, countries downstream also have legitimate claims on a sufficient water supply. It is quite possible that neighbouring countries will demand an increased water level when there is low water (management of lakes and reservoirs) and the supply of greater amounts of drinking water.

In all areas, effects on mitigation policy have been identified. They can partly be influenced, and partly not. Relevant sustainable strategies will have to be developed well in advance. Important points are: Who has claims on water, who will pay how much? In dealing with these, consumers (irrigation, drinking water), users (cooling water, hydroelectric power production) and nature will have to be considered. Will an individual canton or the Federation decide on the supply of significant amounts of drinking water to neighbouring countries? Who will negotiate with neighbouring countries who border on waterbodies regarding claims on overall water management?

5. Space

The spatial planning and building sectors have to adapt to the expected changes, to take action in good time and to make the necessary adjustments. Transport networks and infrastructure are exposed to increased dangers due to climate change.

The spatial structure of Switzerland determines the framework conditions for society and its robustness or susceptibility to future climate changes. In the area of settlements, buildings and infrastructure changes are associated with very long time scales (typically 30 to 100 years). It is precisely because of the long lead times that spatial planning and building not only face a particular challenge but also an opportunity to focus on sustainability.

Settlement structure

Already today, the settlement structure in Switzerland shows the characteristics of a "Netzstadt". Its development is not primarily determined by climate change but by factors such as demography, economics and the demand for land for settlements. On the other hand, an ecological approach to settlement development could contribute considerably to the attainment of adaptation and mitigation targets. Decentralisation, in the sense of creating strong regional centres with the possibility of satisfying material and intangible needs at a regional level, will shorten transport routes and may increase the degree of self-sufficiency with regard to basic resources such as energy, food and building materials.

Buildings

In buildings of today's standard, the comfort of living and working is affected adversely on hot days if there is no cooling. Good insulation of the building shell not only considerably reduces the energy required for heating but also, above all, for cooling. In summer, heat accumulation will increase, especially in office buildings, since the heat created by people, machines and lighting occurs during the hot time of the day and cannot be dissipated to a sufficient extent from most of today's buildings. In residential buildings, adapted construction can usually make cooling devices unnecessary. In office buildings, the combination of free cooling systems with, for instance, solar cooling offers the possibility of guaranteeing the temperature ranges required to ensure productivity in the workplace with less additional energy. The heat still required should be provided by heat pumps in combination with solar heat, without fossil energy. Geothermal probes can also dissipate the accumulating heat in summer under ground. In addition, measures to protect against direct solar radiation in summer and to protect the building shell against extreme weather events, and the avoidance of extremely exposed locations will become necessary.

Transport networks and infrastructure

Transport networks and infrastructure will be exposed to increased risks due to climate change. In the area of rail traffic, there is the risk of embankment instability, damage to contact wires due to weather events and lateral displacement of rails. Here just as in road traffic, delays due to flooding, landslides and avalanches are to be expected. Besides the immediate damage, there will be an increase in economic losses and costs due to disrupted transport routes and lengthy detours in the affected regions. As well as suitable protection measures, an important anticipatory mitigation measure will consist of generally counteracting a further increase in transport requirement per inhabitant, or achieving a reduction of it via a multimodal, preferably environmentally friendly system of efficient carriers with lowest emissions, in coordination with the development of settlement structure. Extreme precipitation events not only cause damage to obviously exposed areas by flooding but also have indirect consequences, for instance due to increased backwater in sewage systems.

Forest and timber industry

In Switzerland, forests have a wide variety of functions that range from protection zones and the conservation of biodiversity to recreational areas and forestry production. There is consensus that a more intensive use of wood than is practised today is reasonable and desirable for sustainable forest management. Energy wood can make a contribution to the electricity and fuel supply in Switzerland from domestic regenerative energy, which should be utilised in order to increase the degree of self-sufficiency, diversification and therefore security of supply. This would be of greater importance quantitatively, if energy production efficiency were generally increased at the same time. Qualitatively first-class wood as a raw material in the building and other industries can additionally replace emissions from fossil fuels, which quantitatively would be of even greater importance. It is therefore the responsibility of spatial planning to set aside protection and recreational areas on the one hand, and on the other to make possible reasonable timber production in the remaining forest areas for the forest and timber industry, wherever economically and ecologically suitable.

Agriculture

Agriculture has an important role in the sustainable design of the Swiss ecosystem. The production of staple foods will be primarily influenced by the opening of markets but also by the changed climatic conditions (summer drought periods). Arable farming will become more difficult, fodder production, which is important to Switzerland, may profit. The extensive cultivation of second-generation energy crops, with their modest need for soils, fertilisers and water, will remain a niche production. The breeding of agricultural crops adapted to the climate will gain great importance.

6. Changes for humans

More frequent heat waves will negatively affect health. In addition, especially during hot spells, a noticeable decrease in human efficiency and productivity is to be expected.

What are the most important changes for humans? What effects will climate change have on life in Switzerland in the year 2050? Without claiming to be comprehensive, the following lists some already foreseeable changes:

Climate affects attitude to life. The experience of the summer of 2003 showed that during periods with hot days and warm nights, the lifestyle of the Swiss becomes more Mediterranean. During the day, people will increasingly prefer to stay in cool interior rooms and in the shade. Life outside will take place more and more in the evening hours. People who enjoy summer will benefit at first, however, more frequent hot summers are expected to become a burden to a growing proportion of the population.

Winter sport will have to come to terms with worse conditions. Increasing precipitation with simultaneously higher temperatures means that there will be more rain in the midlands. Regular winter sport will be possible only at higher elevations. The expensive infrastructure and the long journey will make snowboarding and skiing even more expensive pleasures.

Above a certain temperature, efficiency is affected. In particular during hot spells in summer, a noticeable decrease in human efficiency and therefore in economic productivity are to be expected. The working environment will adapt to the increase in heat waves. In the service sector, people will increasingly be working in air-conditioned offices. Work outside may be interrupted (siesta) during the midday heat. Some businesses could increasingly close for holidays in midsummer and try to postpone particular kinds of work until cooler periods.

The increase in heat waves will have an adverse effect on health. The incidence of food-borne diseases will also increase with the increase in temperatures. This will primarily affect physically and mentally impaired people, the elderly suffering from chronic illnesses, and people who are economically disadvantaged.

As a result of the warming and the increase in hot spells, the quality of living conditions will decrease in older buildings (flat roofed buildings from the 1970s) during the summer months. The demand for comfortable modern apartments with a good room climate will increase. Inhabitants of older buildings will increasingly install mobile air conditioners and power consumption for air conditioning will increase. At the same time, rising energy prices and local, temporary water shortages will lead to a more economical use of resources.

7. Concluding remarks

Most changes that are described in this report may initially seem unspectacular and at first sight unimportant. But this should not hide the fact that many changes only show their true extent when more closely examined; they are cumulative, sometimes irreversible and only herald other changes still to come. In addition, they do not represent stable conditions but merely present a snapshot of the development towards far more drastic changes.

Climate generally changes only slowly. Delayed effects are not yet visible and are only now coming into being. An illustrative example of this is the runoff in catchment areas that today are strongly shaped by the summer glacier melt. In the medium term, the runoff will increase in spite of decreasing summer precipitation due to the accelerated glacier melt. However, in the second half of this century, many small and medium-sized glaciers will already have disappeared and the supply of glacier water will cease entirely (depending on the situation in individual valleys and catchment areas). In combination with reduced summer precipitation, this will lead to a considerable decrease in discharge in summer. A summer in 2050 with temperatures similar to those in 2003 would accordingly result in much more serious water shortages than was the case in 2003. Towards the end of this century, without effective climate protection, most of the large glaciers will also melt so that even "Europe's water reservoir" could regularly suffer from water shortage.

Switzerland has a long tradition of adaptation to natural hazards. Floods, landslides and rockfalls have shaped our landscape and our handling of it. Over the centuries, we have settled in mountain valleys and along rivers at locations where the risk is lowest. Settlements and transportation routes have been protected against floods, rockfalls and avalanches by means of protective structures. The assumed stability of the hazard situation will change with climate change, so that its periodic re-examination will be particularly necessary for settlements and transportation routes in the mountains.

In the future, our country will continue to have the financial means and the technological know-how to adjust to the changed conditions if they do not exceed a certain extent. These adaptation costs will increase in the coming years. We will be able to choose between different strategies and it will be important to assess the various possibilities against the background of all possible effects. It will be indispensable to have a long-term climate strategy, which will include climate protection targets (by emission reductions) as well as targets for the adaptation to changed climatic conditions and protection against changed natural hazards, in order to effect a coherent climate policy.

Switzerland will also be affected by the global effects of climate change. Firstly, we will be directly affected due to our trade relations and dependence on raw material suppliers in various

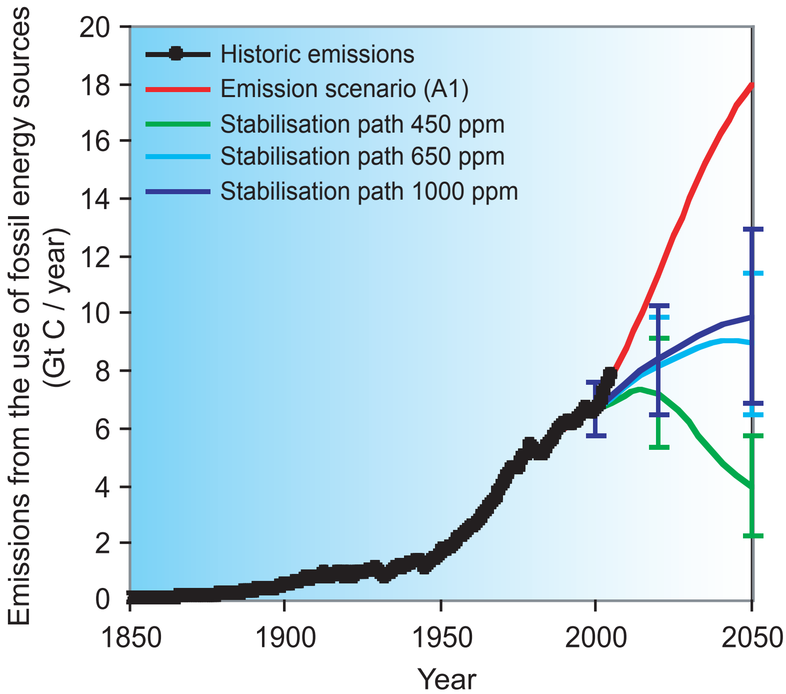

Figure 1: Emission trends according to different emission scenarios. A1 approximately describes today's rapidly growing global economy with a mix of energy sources. In this scenario, the temperature will continue to increase very rapidly for centuries. The other scenarios assume a stabilisation of greenhouse gases at 450 ppm, 650 ppm and 1000 ppm with a temperature increase of about 2 °C, > 3 °C and > 5 °C (pre-industrial CO2-concentration ~280 ppm).
Source: M.R. Raupach, 2006[5])

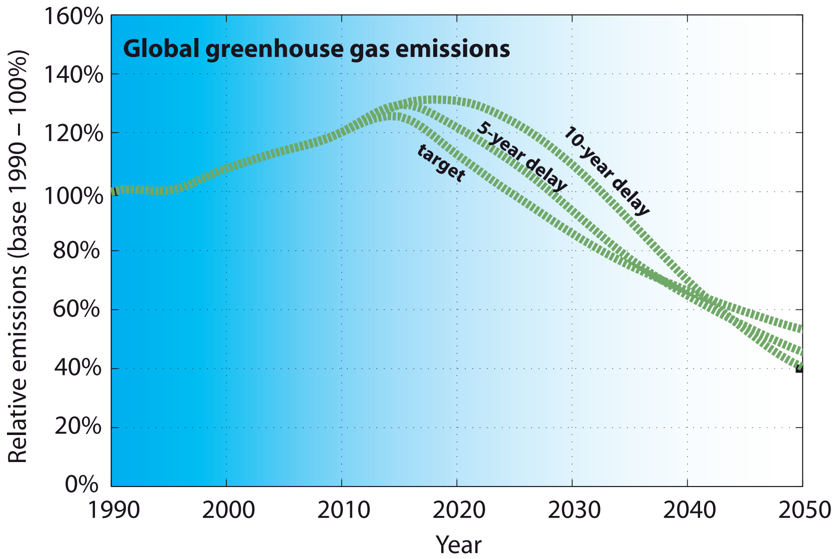

Figure 2: In order to stabilise the global temperature at +2 °C (by 2100), a reduction of global greenhouse gas emissions by 50% (based on 1990 levels) will be required by 2050. This demands immediate action. A delay in taking reduction measures will require a greater and more rapid reduction of emissions in order to reach the target. Thus, annual reduction rates will have to be increased by about 1% for every 5 years of delayed reduction measures.
Source: Modified from Meinhausen et al.[5] and Elzen & Meinhausen[6])

world regions where climate damages may be critical. Secondly, our country will be affected as part of the global economic system, which could suffer considerable damage through climate change. International studies (e.g. Stern review, 2006)7 estimate the economic damage due to climate change at 3-20% of the global GNP by 2100. Damage of such an extent would destabilise the global economic system. This would probably also lead to considerable social upheavals, massive population movements and global political conflicts (among others about water), which might well also gravely affect the Swiss economy.

The only long-term way of limiting the extent of climate-induced consequences consists of combating climate change as the cause. In this regard, the international community is attempting a first step towards a more climate-friendly future with the Kyoto protocol. However, it has always been clear and is now quite evident that these efforts will fall short. Global emissions are currently increasing by 3.2% per year and are developing according to scenario A1 (fig. 1, fossil energy mix). Unfortunately, there are few signs of a comprehensive turnaround towards an improvement in climate change policy. This is, however, urgently required, if a stabilisation target in accordance with the UN climate convention of 1992, which aims to prevent dangerous anthropogenic disturbances of the climate system, is to be attained. The earlier action is taken, the smaller the effects on the climate system and the global economy can be expected to become. However, if emission-reducing measures are delayed, then the reductions required will have to be achieved within a shorter time. Additionally, massive damage will have to be compensated. This can become an unsolvable task, since the economy would have to change over to low-emission production in a very short time. This fact is clearly shown in figure 2.

Therefore, hope remains that on a national as well as on an international level, the decision makers in politics and the economy will recognise the full extent of the problem and manage to decide on a concerted, consistent course of action. It is an open question, to what extent purely economic considerations will play a role in this or whether ethical aspects will also be taken into consideration, and the answer will vary according to the particular point of view. However, it is generally acknowledged as a precautionary principle that today and in the future, the feeling of responsibility towards humans and the environment, which is of particular importance in climate protection, must play a more central role in relation to our actions. Only with adequate foresight will we succeed in reacting adequately and in time to the challenge posed by climate change.

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