Summary

The CH2014-Impacts initiative is a concerted national effort to describe impacts of climate change in Switzerland quantitatively, drawing on the scientific resources available in Switzerland today. The initiative links the recently developed Swiss Climate Change Scenarios CH2011 with an evolving base of quantitative impact models. The use of a common climate data set across disciplines and research groups sets a high standard of consistency and comparability of results. Impact studies explore the wide range of climatic changes in temperature and precipitation projected in CH2011 for the 21st century, which vary with the assumed global level of greenhouse gases, the time horizon, the underlying climate model, and the geographical region within Switzerland. The differences among climate projections are considered using three greenhouse gas scenarios, three future time periods in the 21st century, and three climate uncertainty levels (Figure 1). Impacts are shown with respect to the reference period 1980-2009 of CH2011, and add to any impacts that have already emerged as a result of earlier climate change.

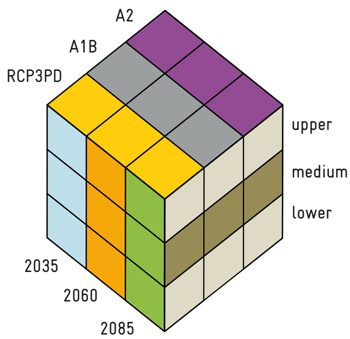


Figure 1: "Scenario cube" mapping the CH2011 scenario space. Scenarios of anthropogenic greenhouse gas emissions include A2 (high emissions, no intervention to reduce climate change), A1B (intermediate emissions, no intervention), and RCP3PD (low emissions due to an effective mitigation policy; referred to as RCP2.6 in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, here RCP3PD is used for consistency with CH2011). Time periods are 30-year averages centered on the years 2035, 2060, and 2085. Climate projections of temperature and precipitation with respect to the reference period 1980-2009 include a medium estimate, and an uncertainty range from upper to lower estimates, with an estimated 2/3 chance of covering the true temperature change, and an estimated 1/2 chance of covering the true precipitation change.

‹ Snowmaking may allow high-elevation ski resorts to mitigate the impact of climate change on the duration of the business season (artificially snowed ski run at Savognin on January 9, 2011; photo: Keystone).

MORE TROPICAL NIGHTS AND LONGER GROWING SEASON

The implications of climate change for Switzerland are first depicted using derived statistics (climate indices) such as "tropical nights" or "growing season length". CH2014-Impacts projects a roughly twofold increase in the number of "summer days", and the common occurrence of "tropical nights" for the lower parts of Switzerland in non-intervention scenarios (A1B and A2, period 2085; Figure 2). This suggests opportunities for tourism and recreation, but poses challenges for health, agriculture, forestry, and biodiversity. In the same scenarios, the domain of frequent "frost days" retreats to higher elevations, highlighting the hazards of permafrost thawing, while "ice days" become rare in the low elevations, potentially benefitting traffic safety and human health. An increase in the "growing season length" holds promise for agriculture, but has uncertain consequences for ecosystem biodiversity. A lower number of "heating degree-days" contrasts with a higher number of "cooling degree-days", in a shift that may deeply affect the important energy demand for space heating and cooling.

CH2014-Impacts complements this general picture with detailed quantitative results on specific impacts from a range of fields: cryosphere, hydrology, biodiversity, forests, agriculture, energy, and health. The diverse geography of Switzerland is examined by a combination of local to regional case studies and Switzerland-wide analyses (Figure 3).

- ○
- ● summer days
- ● tropical nights
- ● frost/ice days
- ● growing season length
- ● heating/cooling degree days
- ○
- ○

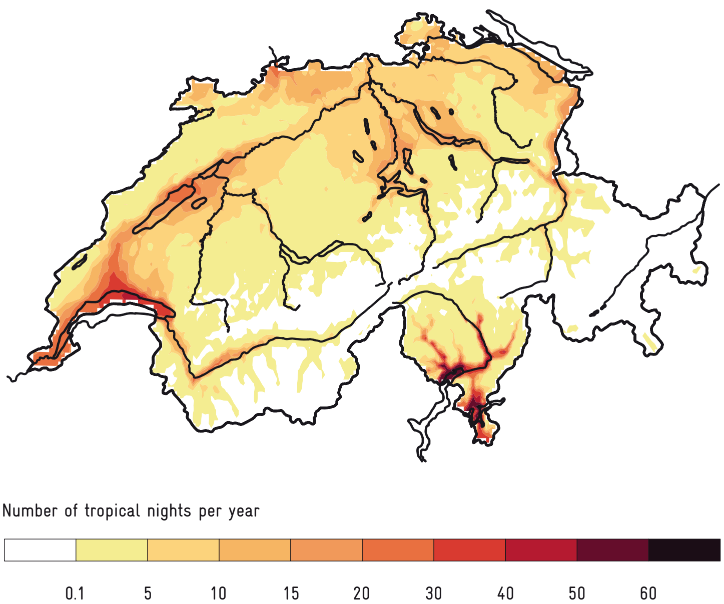


Figure 2: Number of tropical nights per year projected for the end of the 21st century (period 2085, medium estimate) under the A1B climate scenario without intervention to reduce climate change.

LOSS OF GLACIAL ICE AND CHANGES IN RIVER RUNOFF REGIMES

According to non-intervention scenario projections (A1B or A2, medium estimate), snow on the Swiss Plateau will seldom last for several days by the end of the century (Figure 3). Mountain ski resorts face shorter business seasons in all scenarios and time periods considered. Artificial snow mitigates this impact to a considerable extent. Unless constraints on resources and social acceptance prove too limiting, snowmaking may even allow high-elevation resorts to enhance their competitiveness under moderate climate change as projected for the mitigation scenario RCP3PD, or until the mid-century for the non-mitigation scenarios A1B and A2. Based on the simulation of a representative selection of 50 Swiss glaciers, a near-complete loss of glacial ice by the end of the century is projected under the A1B scenario (Figure 3).

- snow cover
- winter tourism
- glaciers
- permafrost

In catchments with little glacial influence, runoff regimes are projected to shift from snow controlled to rain controlled. This results in a change in seasonality, with lower summer runoff and higher winter runoff, but little change in the annual sum (Figure 3). Effective climate change mitigation (scenario RCP3PD) avoids about half of the potential impact as projected under non-mitigation scenarios (A1B and A2). Decreasing summer runoff may lead to an increasing need to manage the competing uses of this resource.

- river runoff
- groundwater temperature

The temperature of groundwater is projected to rise, especially where groundwater is recharged by river water (Figure 3). This warming may lead to the deterioration of groundwater quality. For the strongest warming considered (scenario A2, period 2085), the projections range from a marginal cooling to a warming of up to 7°C. This large uncertainty results mainly from impact modeling.

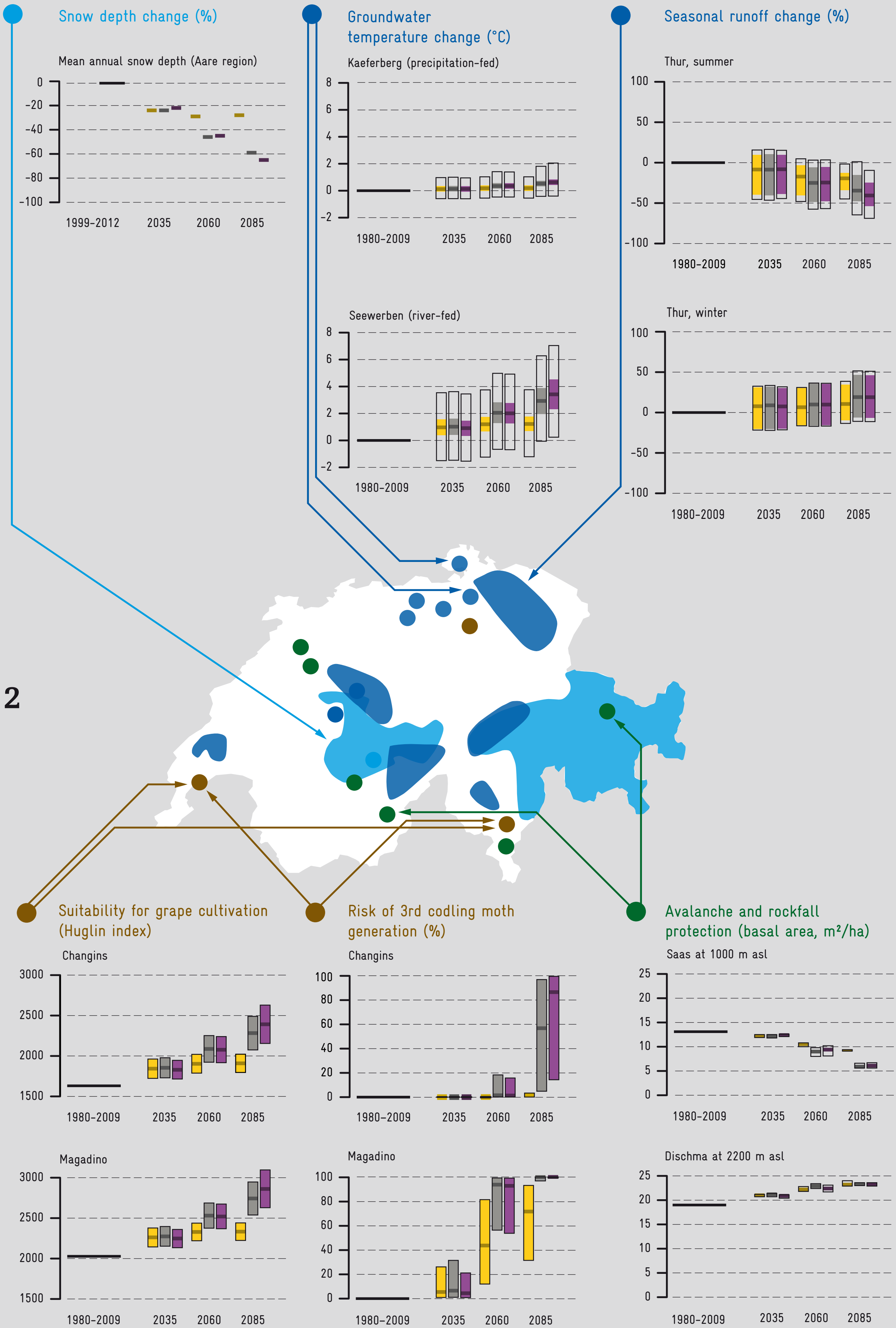
MIXED IMPACTS ON BIODIVERSITY, FORESTS, AND AGRICULTURE

Throughout Switzerland, the diversity of widespread bird and plant species is projected to change under the non-intervention scenario A1B. Losses of currently common species occur on the Swiss Plateau, with its comparatively small altitudinal range. Conversely, species richness increases at intermediate elevations. Both trends imply a “turnover” as species assemblages change in composition (Figure 3), and signal the importance of the management and conservation of biodiversity and ecosystem services.

- bird and plant species

The growth of many major tree species is projected to suffer from drought. Under unmitigated climate change (scenario A1B), the Swiss Plateau may become climatically unsuitable for the now widespread spruce and beech. Moderate warming (period 2035 or mitigation scenario RCP3PD up to period 2085) can benefit forests in terms of biomass at locations where low temperatures currently limit growth and where precipitation is abundant enough to satisfy the increased water demand resulting from higher temperatures. Forests at high elevations

- tree species
- forest properties
- ecosystem services



Snow depth change (%)
Mean annual snow depth (Aare region)
0
-20
-40
-60
-80
-100
1999-2012
2035
2060
2085
Groundwater temperature change (°C)
Kaeferberg (precipitation-fed)
8
6
4
2
0
-2
1980-2009
2035
2060
2085
Seewerben (river-fed)
Seasonal runoff change (%)
Thur, summer
100
50
0
-50
-100
Thur, winter
Suitability for grape cultivation (Huglin index)
Changins
3000
2500
2000
1500
Magadino
Risk of 3rd codling moth generation (%)
Changins
100
80
60
40
20
Magadino
Avalanche and rockfall protection (basal area, m²/ha)
Saas at 1000 m asl
25
20
15
10
5
Dischma at 2200 m asl

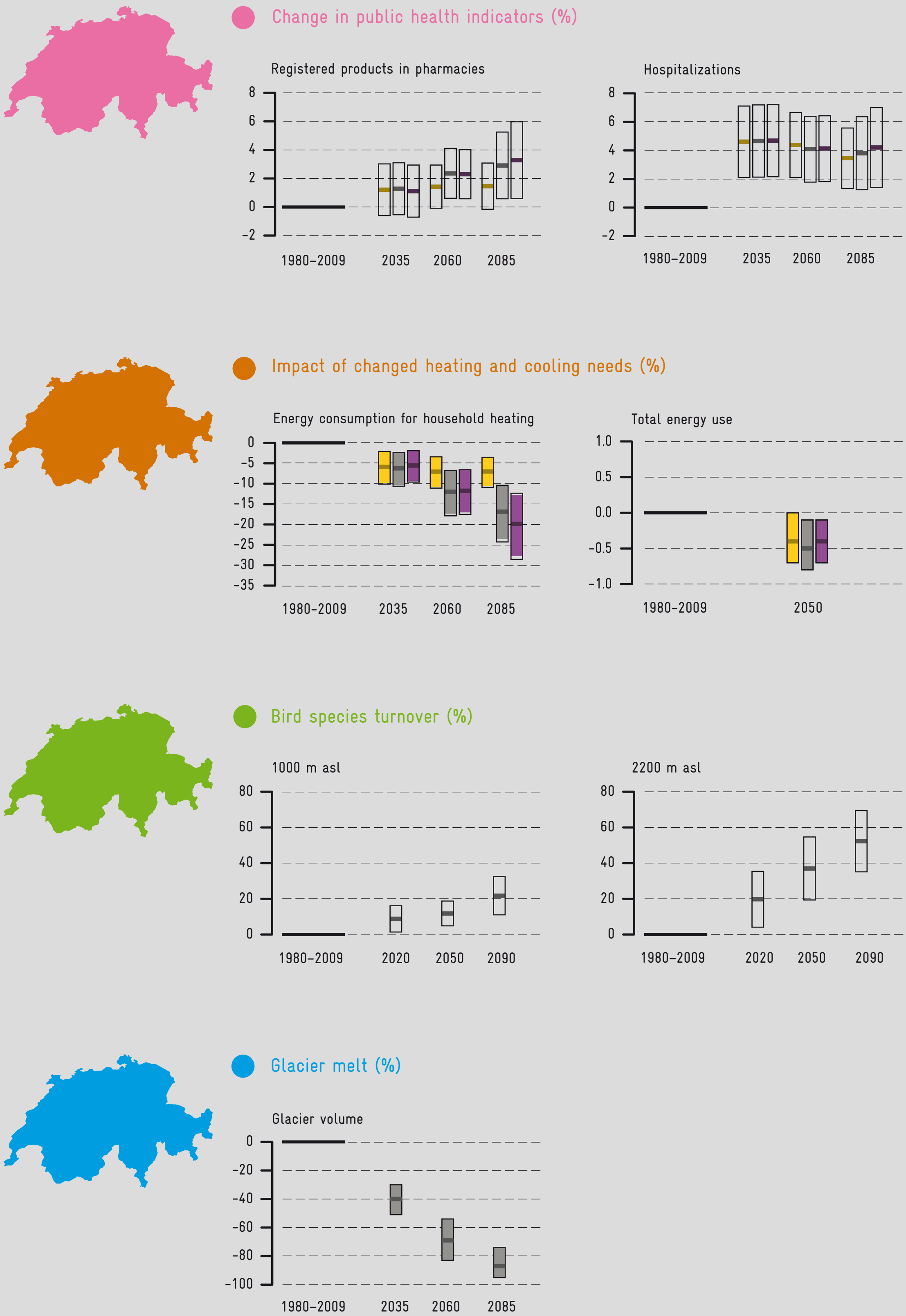


Figure 3: Selected climate change impacts. Greenhouse gas scenarios are indicated in yellow (RCP3PD), grey (A1B), and purple (A2); bold colored lines correspond to the medium climate change estimate, and the low-high climate uncertainty range is shown as a colored bar where an estimate is available. Black outlines include the impact modeling uncertainty to the extent that it is considered in each study (2 standard deviations for statistical estimates). Time ranges slightly deviating from the standard scenario periods were used for bird species turnover (20-year means) and energy impacts (year 2050).

(Dischma valley) respond with stable or enriched tree species diversity and larger biomass across the full range of scenarios. Forests at low elevations in dry inner-Alpine valleys (such as the Saas valley) are, however, sensitive and deteriorate even under moderate warming. Timber production potential, carbon storage, and protection from avalanches and rockfall are forest ecosystem services that reflect differences in the response of forests to climate change. There is an overall tendency to deteriorate at low elevations and improve at high elevations (Figure 3). Climate change will also affect forests indirectly by increasing the risk of infestation by spruce bark beetles, as indicated by the number of potential generations per year (e.g., from currently two at most to three by 2085 for scenario A1B; Figure 4).

Adverse, but potentially manageable developments, are seen in temperature-related impacts such as the incidence of agricultural pests or heat stress suffered by cattle. The risk of the codling moth (an apple pest) developing a third generation is expected to become substantial toward the end of the century in non-intervention scenarios for locations on the Swiss Plateau, and earlier for any scenario in the Ticino (Figure 3). A potentially beneficial impact on agriculture is the wider range of cultivable grape varieties as a result of higher temperatures. These findings are in line with earlier assessments that found, on balance, beneficial impacts on agriculture under the moderate degree of climate change projected for the first half of the century. Negative effects are, however, expected to dominate in the long term as climate change progresses, except for the case of effective mitigation (scenario RCP3PD).

○
● heat stress in cattle
● pest phenology
● wine production
○

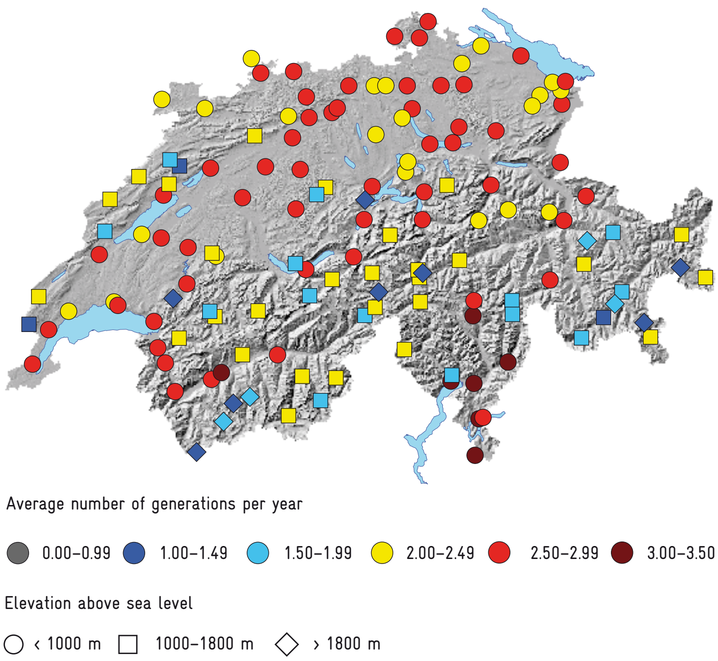


Figure 4: Potential generations of spruce bark beetles per year projected for the end of the 21st century (period 2085) under the A1B climate scenario without intervention to reduce climate change.

LESS ENERGY FOR HEATING BUT MORE FOR COOLING

energy for heating/cooling
effect on total energy use and GDP

Decreasing heating degree-days and increasing cooling degree-days indicate the heating energy saved, or cooling energy needed to maintain the indoor climate under changing ambient temperatures (Figure 3). The observed energy consumption for heating in households over the years 2000 to 2010, however, exhibits only 50% of the variation seen in heating degree-days (direct rebound effect). Applied to the future this means that only half of the potential energy saving is realized. A cross-sector analysis with a computable general equilibrium model suggests that the remaining 50% saving is largely absorbed by the consumption of other goods (indirect rebound effect), leaving a modest reduction in total energy consumption (<1%) and a small welfare gain (<0.25% of GDP) for the A1B scenario at mid-century. Increased need for space cooling, though economically detrimental, does not offset the saving from reduced heating.

health indicators

Statistical analysis reveals a relationship between observed weather and indicators of human health for Switzerland (such as sales of registered health products or hospitalizations). By assuming that this relationship remains valid during long-term climate change, and neglecting potential adaption in physiology, behavior, etc., an upper bound estimate of the impact on human health indicators is obtained (Figure 3). The sales of registered health products in pharmacies increase in parallel with warming by up to about 3% (non-intervention scenarios A1B and A2 in period 2085). Hospitalizations show a complex relationship to climate change, increasing by about 4%, with little dependence on the greenhouse gas scenario and time period considered.

IMPORTANCE OF MANAGING CLIMATE CHANGE IMPACTS IN SWITZERLAND

In summary, CH2014-Impacts presents a picture of predominantly adverse consequences of climate change in Switzerland. These include examples of potentially deleterious changes, which can be mitigated and sometimes turned to an advantage if properly managed. This highlights the role of foresight and management in dealing with climate change impacts in Switzerland. Beneficial effects tend to be limited to moderate climate change, underscoring the importance of greenhouse gas emission abatement. Adverse short-term impacts appear limited with respect to the reference period 1980-2009, but will add to any impacts already experienced today as a consequence of climate change over the previous decades.

The impact of severe climate change emerges toward the end of the century, when the scenarios of unabated greenhouse gas emissions (A1B and A2) lose their moderate appearance. Due to the inertia of the socio-economical and physical climate systems involved, an increase in the severity of climate change appears inevitable for these non-intervention scenarios in the 22nd century. In particular, elevated CO_2 concentrations in the