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Experience from downscaling IPCC-SRES scenarios to specific national-level focus scenarios for ecosystem service management

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ABSTRACT

Scenario analysis is a widely used approach to incorporate uncertainties in global change research. In the context of regional ecosystem service and landscape management where global IPCC climate simulations and their downscaled derivates are applied, it can be useful to work with regional socio-economic scenarios that are coherent with the global IPCC scenarios. The consistency with the original source scenarios, transparency and reproducibility of the methods used as well as the internal consistency of the derived scenarios are important methodological prerequisites for coherently downscaling pre-existing source scenarios. In contrast to well-established systematic-qualitative scenario techniques, we employ here a formal technique of scenario construction which combines expert judgement with a quantitative, indicator-based selection algorithm in order to deduce a formally consistent set of focus scenario. In our case study, these focus scenarios reflect the potential development pathways of major national-level drivers for ecosystem service management in Swiss mountain regions. The integration of an extra impact factor ("Global Trends") directly referring to the four principle SRES scenario families, helped us to formally internalise base assumptions of IPCC SRES scenarios to regional scenarios that address a different thematic focus (ecosystem service management), spatial level (national) and time horizon (2050). Compared to the well-established systematic-qualitative approach, we find strong similarities between the two methods, including the susceptibility to personal judgement which is only partly reduced by the formal method. However, the formalised scenario approach conveys four clear advantages, (1) the better documentation of the process, (2) its reproducibility, (3) the openness in terms of the number and directions of the finally selected set of scenarios, and (4) its analytical power.

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1. Introduction

How will climate change and socio-economic transition affect small-scale decision-making in landscape and ecosystem service management? What changes should policy-makers and landowners prepare for in order to ensure ecosystem service

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provisioning? What will the economic, societal and technological circumstances be like in which policy-makers and landowners make decisions on ecosystem service management in the future? A variety of fundamental uncertainties, embracing both the natural and the social system, needs to be considered when addressing these questions.

A valuable and frequently applied technique to investigate the complex uncertainties associated with future changes and their impacts is scenario analysis [e.g. 1,2]. Scenarios have been characterised as the "… plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumption about key driving forces and relationships" [1 cited in 22]. Scenario analysis, as the process of systematically developing and evaluation of possible future developments, was initially used in the field of military actions in the post-war period [3], and has soon been applied also in business [4] and research where global change and its impact on society, nature and the coupled human–environment system have become one of the areas of regular utilisation [e.g. 5].

Since 2000, a multitude of studies have been conducted on climate and global change where the impacts have been assessed on scales that range from global to local [e.g. 6–10]. For such research, climate simulations produced by the United Nations Intergovernmental Panel on Climate Change (IPCC) [e.g. 11] and regional downscaled data [e.g. 12,13] have been a primary source for climate projection. These climate simulation data have initially been built on scenarios published in the IPCC Special Report on Emission Scenarios (SRES) [2]. These so-called SRES scenarios depict several distinct global socio-economic development pathways from which global greenhouse gas emission were deduced. Alternative concepts have been proposed to downscale scenarios depending on the scenarios' role [14], for instance also complementary scenarios at the regional scales which can deliberately build on different reasoning [e.g. 15]. To set the socio-economic boundary conditions for regional analysis when applying regionally downscaled IPCC climate simulations, we argue for consistently deducing these SRES scenarios along with their overall logic to study specific regional scenarios (see Fig. 1). In such cases, coherence [sensu 14] between the independently downscaled scenarios and the source scenarios is essential, so that the they match the source scenarios' logic and focus on interrelated, but not exactly identical uncertainties. Besides consistency [sensu 16] with the original source scenarios, transparency and reproducibility of the methods used as well as internal consistency of the derived scenarios are also further important methodological prerequisites when downscaling large-scale scenarios [17].

Many studies have tried to achieve such consistency between small-scale scenarios and the SRES scenarios. Some studies used spatially explicit, model-based downscaling methods to zoom into individual regions [e.g. 18], some built on joint scenario development across multiple scales [19]. And the majority of landscape management related studies built on different variants of a systematic, but informal approach [20–22] which has been referred to as the "intuitive-logic approach" in the literature [23]. These scenarios have often been combined with model-based simulations of land use change scenarios in the tradition of the story-and-simulation approach where scenario stories and simulations are iteratively combined to reach higher consistency [24].

The "intuitive-logic" approach [sensu 23], which will further be referred to as the "systematic-qualitative" approach to scenario development to better reflect its well-established and systematic procedure, has proven successful in many applications since it has first been introduced in the 1960s [3]. It builds on 10 to 20 main factors, identified as the principle components and drivers of the system under investigation by a group of experts or stakeholders, and their interrelations within the system. Based on group discussion among the experts or stakeholders, two of these drivers are then usually selected as key uncertainties. These two key uncertainties are further used as the two axes of a two-by-two matrix which structures the process of identifying development pathways of the remaining factors along these axes [25]. Consistency, overlap, independency and the degree of separation between scenarios resulting from the choice of key uncertainties is continuously discussed among the groups of experts, and where possible founded on quantitative data. However, the technique has been criticised for its susceptibility to personal judgement and biases due to its strong dependency on expert

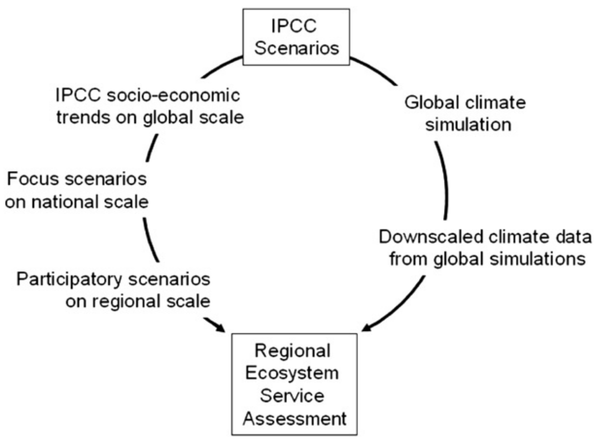

Fig. 1. Concept of the use of scenarios typical for many research projects with a focus on complex human–environment systems. Here we specifically look at the development of the focus scenarios on the national level describing the setting for ecosystem service management in Swiss mountain regions.

judgement [26]. Furthermore, it lacks a formal procedure to ensure consistency between the deduced scenarios with the parent scenarios, except for the choice of the same principle axes along with the scenarios are structured.

Although not yet widely used, alternative approaches to scenario construction suggest a more formal technique, still strongly based on expert judgement, but in combination with mathematical evaluation and optimisation of these judgements with respect to logical consistency [e.g. 16]. Such techniques have been successfully applied in the field of technological advances [e.g. 27,28], and also on human–environment systems [29]. So far, they have not been used to develop scenarios in formal consistence with a set of pre-existing scenarios. In this contribution we investigate, whether we can deduce formally consistent scenarios of a different focus, spatial extent and scale through such a formal technique. We compare how these scenarios compare with scenarios based on the qualitative approach, and evaluate what we can learn from such a formal method of scenario development.

We use Formative Scenario Analysis to develop scenarios focusing on the national-level conditions for the ecosystem service management in Swiss mountain regions [48,49], which are formally consistent with the SRES scenarios based on the terminology in [16]. We will refer to these scenarios as "focus scenarios", and understand them as logically nested within the global SRES scenarios and therefore consistent with the assumptions that lead to the simulated climate data applied in the model-based impact analyses. In our case study, we concentrate on common national-level drivers only. Impacts and responses within the regions are not reflected in the focus scenarios, as regional impact assessment will then be conducted either by follow-up participatory scenario development on the community level [30] or by numerical modelling following the already mentioned storyline-and-simulation approach [e.g. 31,32] (see Fig. 1). The similarities, advantages and disadvantages of the formal technique are discussed in detail, with a particular focus on the formal coherence with the IPCC-SRES scenarios, the internal consistency of the derived set of scenarios and the analytical power of the technique.

2. Methods

Similar to other mathematically based techniques [e.g. 27], Formative Scenario Analysis provides a structured process for the deduction of consistent scenarios while combining mathematical analyses with quantitative and qualitative expert assessment [16].

The basic procedure of Formative Scenario Analysis is to identify relevant drivers for the investigated [referred to as "impact factors" in the remaining article in accordance with 33, 34], to define plausible future states for each of these impact factors [referred to as "levels" in the remaining article in accordance with 33, 34], and then to rate the relationships between impact factors and their future states. Typical also for other formal scenario techniques [e.g. 35], a scenario is defined by a combination of specific future states for each impact factor in Formative Scenario Analysis. Hence, a bundle of scenarios contains several distinct combinations of specific, pre-determined future states of all impact factors included into the overall system.

In mathematical terms, a scenario describes a possible future state of a system by means of impact factors and their future levels. There are different impact factors $y_1,\ldots, y_j,\ldots, y_n$. For each impact factor y_j there are different levels $y_j^1,\ldots,y_j^{m_j},\ldots,y_j^{m_j}$ while the number of levels m_j should be small ($m_j < 5$). The set of all scenarios is then the set of all complete combinations of impact factors [see 33, p. 105].

$$S = \left\{\left(y_1^{m_1},\ldots,y_j^{m_j},\ldots,y_n^{m_n}\right)\middle|1\leq m_j\leq M_j for\, 1\leq j\leq n\right\}. \quad (1)$$

The mathematics behind the method is described in detail in [34]. It has been used in a number of case studies with differing sectoral and regional foci [28,36,37] as well as varying degrees of stakeholder engagement [29].

Typical for the complexity of the problem, the group involved in the scenario development comprised two ecological modellers, a climate data modeller, two agricultural economists, two land use modellers, one political scientist, a resilience researcher and an expert in transdisciplinary research. With this composition, seven disciplines and six institutional groups collaborated closely throughout the development of the scenarios. Besides few meetings, the collaboration within the scenario working group was generally informal and the relevant experts were involved in different combinations (Table A1 in the Appendix).

Our approach following the technique of Formative Scenario Analysis [16] can be divided into five major steps:

2.1. System and goal definition

The system under consideration, and the goals of the scenario analysis, needed to be clearly defined. In particular, the thematic focus, the time horizon and the spatial extent of the scenarios needed to be specified. All three aspects strongly related to the research aims of the MOUNTLAND project, but required exact specifications based on discussions among the researchers.

2.2. Impact factor identification, rating the interconnectedness between impact factors and analysis of the impact matrix

The impact factors, i.e. drivers, to be considered in the analysis needed to be identified, defined and selected. A literature survey on ecosystem service development on the global and European level [20,21,38–40] was performed in order to identify impact factors suitable for the national level of Switzerland and our focus on future ecosystem service management.

After a first literature review, the initial set of impact factors for ecosystem service management in Switzerland was compiled based on a brain storming session during a project meeting including 29 project partners. This large group was subdivided into five groups of five to six persons. At this stage of the project exclusively focusing on the impact factors on the national level was difficult. The collected impact factors were therefore allocated to different spatial levels (i.e. global, EU, and national level), in order to more easily identify the national level impact factors.

We re-organised the initial collection of impact factors from the brain storming session by grouping and classifying them according to the STEEP categories Social, Technological, Economic, Environmental, and Political [e.g. 41]. Based on a discussion within the scenario working group, the factor set was finally reduced to 19 impact factors, maintaining only factors that are (1) acting on the national level only, (2) influence land use or ecosystem service dynamics or factors underlying the latter dynamics, and (3) associated with some major future uncertainty. In addition the set of eight climate parameters was merged to one impact factor "Climate". Each impact factor was defined by the according experts of the scenario working group.

In addition to the national level factors, an extra impact factor was added describing "Global Trends". This "Global Trends" factor represents a combination of the impact factors proposed for the global level and introduces the SRES scenarios into the analysis when defining future levels in the Step 4 of the scenario analysis. Using one single "Global Trends" factor requires profound knowledge of the SRES scenarios from all involved researchers when complementing the impact and the consistency matrices in the following steps. Splitting up the "Global Trends" factor into the specified aspects within the SRES scenarios, however, would have enlarged the matrices considerably, and essential national level aspects would have to be omitted to keep the matrix to a manageable size. The four main SRES scenario storylines [2] are briefly summarised in Box 1.

The assessment of direct, directional impacts between the system variables represents the synthesis process in the scenario construction procedure. Assessing and displaying the causal relation between the variables (1) allows identifying the systemic role of variables, (2) reveals important feedback loops within the system, (3) facilitates interpretation of the final scenarios, and (4) enables formulation of concise storylines thereof [27]. Generally, this step is intended for situations where a "complete" system is represented with the impact factor set. Our focus scenarios, in contrast, were designed to collect only driving forces at national and global level (e.g. agricultural policy), while the response variables (e.g. decision-making on the farm level) required for closing feedback loops formed part of separate local scenarios [30] and modelling endeavours [e.g. 31,32]. Some merits of this impact analysis are therefore realised in subsequent project phases and impact assessments not covered in this publication.

Each expert in the scenarios working group rated the effects of the impact factors related to his or her expertise on all other impact factors on a scale between 0 and 2 (0 = no/very little impact; 1 = medium impact, 2 = strong impact), and provided rationales for the rating based on existing literature and personal expertise. A total of 342 impacts were assessed, with every impact covered by at least three experts. All expert ratings were collected in a single impact matrix. Divergent ratings were discussed to achieve a consensus on impact factors and impact interpretations. For the remaining controversial impacts, two ratings were maintained, reflecting either uncertainty or disagreement between experts. The resulting final two matrices were then analysed to identify particularly active and passive variables within the set, i.e. factors that strongly impact others (active) and the ones that are strongly impacted by others (passive), and secondly strong causalities between impact factors to enhance the interpretation of the final set of scenario. Row and column sums served as an indicator for activity, and passivity respectively.

2.3. Definition of future states and construction of consistency matrix

For each of the impact factors the according working group experts defined two to four plausible future states for 2050 based on a literature review. The impact factors and

Box 1
Base storylines according to IPCC SRES scenarios.

A1 describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2 describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

B1 describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2 describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

their future states were used to set up a consistency matrix. Different to the impact assessment the consistency assessment is non-directional, so the consistency between a future state A and a future state B is judged only once adding up to a total of 1378 consistencies to be assessed.

The consistency of each potential future state of one impact factor with the potential future states of all other impact factor was then rated using a five point scale: Strong conflict, Conflict, Possible, Weak synergy, Strong synergy (translated into numerical values to be used by the analysis software, see Table 1).

The consistency ratings were first assigned by the core team of the scenario working group. This consistency matrix was then checked by the corresponding experts and conflicting judgements were identified. Deviations were discussed and consensual solutions were sought. Due to the complexity of the matrix and the large number of combinations, mostly only one person of the core team and two or three disciplinary experts of the scenario working group were involved in these discussions.

2.4. Consistency analysis and scenario selection

All possible combinatorial sets of future states are considered possible scenarios in Formative Scenario Analysis. A consistency analysis helps to reduce the large number of possible combinatorial sets based on mathematical indicators. The software Systaim KD (Version 5.0) was used to perform this quantitative consistency analysis [34].

The four Consistency Indicators build on the ratings of pairs of future levels. The Consistency Indicators include a) the additive value of the ratings of all future level combinations brought together in a scenario, b) the multiplicative value of these ratings, c) the number of inconsistencies ("strong conflicts") and d) the minimum consistency level occurring in a scenario.

After calculating the Consistency Indicators, the superiority of a scenario is measured by its "Local Efficiency". The local efficiency of a scenario is defined as the number of neighbouring scenarios (scenarios with only one different future level) with lower or equal consistency and indicates how unique a scenario is within the dataset. Eight Local Efficiency Indicators are defined building upon the four Consistency Indicators, by either counting only the scenarios which are "less consistent" to the one assessed, or by counting the ones that are "less and equally consistent". The Local Efficiency Indicator LE2, referred to later in the results section, is based on additive consistency and only the less consistent scenarios. For more details, please refer to [34].

Consistency and Local Efficiency Indicators are calculated for all possible combinatorial sets of future levels. Then only the locally efficient combinations are selected while all other combinatorial variations are omitted. Further, an optimisation algorithm ranks the remaining combinations based on the Consistency and the Local Efficiency Indicators [34].

Table 1
The scale of rating consistency between future levels, including the additive and the multiplicative values used to derive Consistency Indicators.

Name	Additive value	Multiplicative value
Strong conflict	−2	0.0
Conflict	−1	0.5
Possible	0	1.0
Synergy	1	2.0
Strong synergy	2	3.0

2.5. Final scenario selection and interpretation

The optimisation algorithm suggests a small selection of scenarios. The final selection of four out of the eight suggested scenarios was then conducted in a non-automated way, again with the goal of selecting scenarios with higher variation between future levels for the individual impact factors and strong internal consistency. The final selection of scenarios was discussed, labelled and finally approved in a procedure of several feedback loops in the scenarios working group.

After consolidating the final set of scenarios, storylines were elaborated to ease communication within the project team and to stakeholders from the three case study regions and at higher administrative levels.

3. Results

3.1. System and goal definition

The thematic focus of the scenarios had to be strongly related to the overall research aims of the MOUNTLAND project. Hence it was defined as "the conditions which ecosystem service management in mountain regions would be affected by in the future". Similarly the spatial extent of the scenarios was strongly related to the MOUNTLAND research sites, the project conducted research in three mountainous case study regions within Switzerland, located in three different federal states (cantons) and in two different mountain ranges (Alps and Jura). So, the national level was chosen to develop common political and socio-economic scenarios with relevance for all three regions, which then also could be used as boundary conditions for the regional modelling. The time horizon had to be aligned with present-day decision-making in ecosystem service management. 2050, and thus an almost 40 year period, was agreed to be a reasonable timeframe.

3.2. Impact factors and analysis of impact matrix

The final set of impact factors and their definition is shown in Table 2, with details on the impact factor "Climate" specified in Table 3. Seven social, one technological, four economic and five political impact factors and the "Global Trends" factor indicating major global developments based on IPCC emission scenarios were identified to be crucially important for ecosystem service management in Switzerland over the next four decades. The possible future states for each of these impact factors are described in Table 2.

The analysis of the rated impact matrix identified "Global Trends", "Energy market & prices", "Climate", "Economic Growth in Switzerland" and "Climate Protection Policy" as the most active impact factors for adapted management of ecosystem service in the future. The most passive factors in the set are "Nature Conservation" and "Natural Resource Management". The impact factors most involved in feedback loops are "Natural Resource Management" and "Spatial Planning Policy". However, in the present study these results are of minor relevance as local impacts and adaptations are

Table 2
Final set of impact factors (IF), their definitions and brief description of future states (FS). More details on future states are provided in the Supplementary material. See Table 4 for details on the impact factor climate.

Type of IF	Impact factors	Definition and brief description of future states	Number of FS
Social	PopCH	Population development of Switzerland including demographic aspects also such as age structure with (1) constant population of 7.5 Mio and (2) population increase to 9.5 Mio.	2
	MigCH	Population distribution within Switzerland with an emphasis to the low- and upland migration, namely (1) amenity migration into the mountain regions with intensive exchange with the lowlands, (2) development of the Regional centres in the mountains, and (3) migration towards the lowland agglomerations.	2
	Accessibility	Degree of increasing accessibility by road and rail network with (1) no, (2) moderate and (3) high increase in accessibility of mountain regions.	3
	Tourism	Major trends in tourism development, with a major emphasis on the differentiation of (1) land and resource intense mass tourism and (2) regionally based sustainable tourism	2
	EnvAwaren	Trends in environmental awareness of the public, with respect to rising interest in (1) technological solution, (2) low-tech solutions and (3) resignation and a decrease of interest	3
	ConsumpPatt	Trends in prevailing consumption patterns with respect to either (1) certified organically grown products, (2) regional products, and (3) global production.	3
	NatResourceMan	Trends in natural resource management differentiating between (1) conscious/sustainable and (2) exploitive/indiscriminate use.	2
Technol.	TechInnovAgri	Degree of technological innovation in agriculture with relevance for productiveness, efficiency and costs, with (1) low and (2) high increase of technological innovation.	2
Environm.	Climate	Coherent sets of several climate parameters (air temperature, precipitation, atmospheric CO_2, radiation, the frequency of disturbances i.e. heat waves and droughts) based on regionalised IPCC climate simulations (REMO/ECHAM5) with A1B, A2 and B1 referring to according SRES scenarios* (more details in Table 4).	3
Economic	EconGrowthCH	Rate of economic growth in Switzerland with (1) moderate economic growth at recent levels and (2) high economic growth.	2
	AgriMarketsPrices	Trends in end-user prices of agricultural commodities controlled by global and national demand as well as national agricultural policy, with possible (1) decline, (2) increase, and (3) strong increase in prices	3
	EnergyMarketsPrice	Trends in energy consumption depending mainly on technological advances and consequent reduction in fuel demand as well as type and intensity of industry and life-styles, with possible (1) slight increase, and (2) strong increase.	2
	WoodMarketsPrices	Trends in prices for wood for the end-user depending mainly on energy prices and the use of wood as fuel, with (1) status-quo, and (2) strong increase in price.	2
Policy	NatCons	Trends in nature conservation with either (1) an expansion, (2) status-quo, or (3) reduction in protected area.	3
	PolEmissionRed	Degree to which the federal government commits itself to the reduction of greenhouse gas emissions with (1) moderate and (2) ambitious reduction targets.	2
	PolSpatPlan	Trends in spatial planning policies with (1) laisser-faire, (2) status-quo and (3) more restrictive planning.	3
	AgricPolicy	Trends in agricultural policy with (1) greening by supporting of ecological and societal performances, (2) protectionism through an orientation towards productivity and (3) liberalisation and further deregulation.	3
	PolEnergy	Trends in federal energy policy with the options (1) business-as-usual, (2) increased cooperation between government and economy, (3) setting of new priorities, and (4) 2000-Watt society.	4
EXTRA	Global Trends	Major global development trends, in our case study the four trends differentiated in the IPCC emission scenarios along the axis of (1) exploitive economy versus greening of the economy and (2) globalisation versus regionalisation	4

*Downscaled climate data was not available for IPCC scenario B2, still we kept B2 as a "Global Trend" for framing assumptions in ecological, land use and agricultural modelling, as well as for the evaluation of policy options.

Table 3
The input parameter set represented by the impact factor "climate" including values for the three downscaled IPCC scenarios based on REMO/ECHAM5 simulation runs.

		A1B		A2		B1	
		2040–2060	2080–2100	2040–2060	2080–2100	2040–2060	2080–2100
Temperature	Dec–Feb	+2.2 °C	+5.0 °C	+2.0 °C	+4.1 °C	+1.2 °C	+2.8 °C
	June–Aug	+2.3 °C	+5.1 °C	+2.5 °C	+5.1 °C	+1.7 °C	+3.3 °C
Precipitation	Dec–Feb	−1.4 mm	+8.9 mm	+2.9 mm	+18.6 mm	+8.9 mm	+11.4 mm
	June–Aug	−8.1 mm	−31.7 mm	−6.6 mm	−34.9 mm	+1.1 mm	−17.0 mm
Solar radiation [cloud cover]	Dec–Feb	+4.7%	+7.5%	+3.7%	+1.3%	−0.6%	+2.1%
	June–Aug	+0.8%	+6.8%	+2.5%	+6.8%	−1.0%	+4.2%
Wind speeds	Dec–Feb	+0.2%	+3.2%	+0.8%	+6.0%	+2.2%	+3.1%
	June–Aug	−0.9%	−5.6%	−2.2%	−5.8%	+1.2%	−3.8%
Droughts [drought levels]			+8%		+14%		+12%
Heatwaves [heatwaves per year]		5, 4	11, 2	5, 5	10, 1	3, 8	6, 9
Heatwaves [days per year]		46, 5	117, 3	49, 2	111, 5	31, 4	63, 7
Wildfires [area damaged by fire]		+17%	+27%	+13%	+22%	+10%	+17%

With drought level defined as Actual Evapotranspiration/Potential Evapotranspiration [based on 29 and 30], and heatwave defined as at least N consecutive days with $T_{max} > T_{max\_runningmean} + T$ °C [based on 29 and 30], with N = 6 and T = 5.

not explicitly embedded into the investigated system. These will be covered in later, partly model based investigations of the overall project [e.g. 30–32,42]. Furthermore, a merged set of impact factors from the national level focus scenarios with impact factors describing land use decision making in the MOUNTLAND case study region Valais was analysed and showed that all variables identified as active in the focus scenarios remain strongly active in the merged set.

3.3. Consistency analysis, scenario selection and interpretation

Based on the ratings of the consistencies between all combinations of future levels (see consistency matrix Table A2 in the Appendix), the consistency analysis suggests 50 locally efficient sets of scenarios, from which eight were selected through the optimisation algorithm based on a combination of Consistency and Local Efficiency Indicators. Among these suggested scenarios all four future levels of the “Global Trends” variable were represented. Using the described criteria for the final non-automated selection, the final set of focus scenarios includs four scenarios with each of them showing a different future state of the impact factor “Global Trends” (Table 4 with storylines describing the future states of the each single impact factor for the year 2050 in Box 2).

Future states that occur only in one of the four scenarios (highlighted in Table 4) contribute strongly to the profile of the according scenario. Each of the selected scenarios contain several unique future states, with scenario “Growth and Convergence” and “Regional Centres” showing six unique future states, “Green Growth” showing five and “Local Sustainability” showing four unique levels.

The internal consistencies of these finally selected scenarios prove high with additive Consistency Indicators between 81 and 91 for three scenarios and 69 for the least consistent scenario (Regional Centres). Also the variation between them is considerable with the Local Efficiency Indicator LE2 between 30 and 33. Within the final set of scenarios, however, we find one combination of future level that had been rated as inconsistent (“strong conflict”). This is the combination of “Amenity Migration” and “Strict Spatial Planning” in the “Green Growth” scenario, which will be referred to in the Discussion section again.

4. Discussion

4.1. Degree to which focus scenarios are nested in SRES scenarios

Due to the formal integration of the “Global Trends” variable and according future levels corresponding with the global SRES scenario families (i.e. A1B, A2, B1, B2), the derived national-level focus scenarios are well nested in the global framing scenarios. The complexity of the impact factor “Global Trends” led to a strong interconnectedness of the variable to all other variables and polarising values in the consistency matrix. Consequently, it dominated the combinations of future levels after the mathematical optimisation. The automated selection of the highest ranking scenarios in terms of consistency and degree of variation included scenarios covering each of the four future levels of the “Global Trend” impact factor. The method, thus, was efficient in producing focus scenarios formally linking to the higher-level SRES scenarios. This result suggests that Formative Scenario Analysis might be a valid technique also in other cases when scenarios need to be developed consistently with a set of pre-defined scenarios, either of a different spatial extent, scale or thematic focus.

4.2. Key difference between Formative Scenario Analysis compared to systematic-qualitative scenario approach

The key difference of Formative Scenario Analysis compared to less formal scenario development is the systematic break-down of a complex system into single one-by-one combinations of impacts and future states. This reduces the

Table 4
The final set of scenarios for 2050, each set represents a distinct combination of future levels. Future states that occur only in one of the four selected scenarios are highlighted in bold.

	Growth & convergence	Regional centres	Green Growth	Local Sustainability
Global Trends	**A1B**	**A2**	**B1**	**B2**
Climate	**A1B**	**A2**	B1	B1[a]
Population CH	9.5 Mio	7.5 Mio	9.5 Mio	7.5 Mio
Migration within CH	**Migration to agglomeration**	Regional centres	**Amenity migration**	Regional centres
Accessibility of mountain regions	High increase	High increase	**Moderate increase**	**No increase**
Tourism development	Exploitive	Exploitive	Sustainable	Sustainable
Natural resource management	Exploitive	Exploitive	Sustainable	Sustainable
Environmental awareness	Technical solutions	**No interest**	Technical solutions	**Low-tech solutions**
Consumption patterns	**Global production**	Regional products	**Certified products**	Regional products
Economic growth	High increase	Moderate increase	High increase	Moderate increase
Agricultural markets	**Decline in prices**	High increase in prices	**Small increase in prices**	High increase in prices
Wood prices	Stable prices	Stable prices	Increase in prices	Increase in prices
Energy consumption	Stable consumption	**Rising consumptions**	Stable consumption	Stable consumption
Technol. innovation in agriculture	High innovation rate	Low innovation rate	High innovation rate	Low innovation rate
Energy policy	New priorities	**Business as usual**	New priorities	**2000-Watt society**
Nature conservation	Reduction	Reduction	Extension	Extension
Climate policy	Low emission reduction aims	Low reduction	Strong reduction	Strong reduction
Spatial planning policy	Laisser-faire	Laisser-faire	Restrictive	Restrictive
Agricultural policy	**Liberalisation**	**Protection**	Greening	Greening

[a] Downscaled climate data was not available for IPCC scenario B2 within this project.

Box 2
Storylines of the four selected scenarios representing the conditions for future adapted management of ecosystem services in Swiss mountain regions.

Growth & convergence
Global development is characterised by very rapid economic growth with a convergence among regions and climate change according to the A1B scenario of the IPCC*. Also in Switzerland economic growth is high, and natural resource management is exploitive. As road and rail networks are improved, the accessibility of remote and mountain regions increases strongly within Switzerland, and in combination with rather loose spatial planning policy, this encourages exploitive tourism. The agglomerations grow, while remote mountain regions undergo decline in population. Environmental awareness focuses on technical solutions, and efforts in nature conservation are reduced. Agricultural policy is liberal and technological innovation in agriculture is high. Mainly globally produced goods are consumed and end-user prices of agricultural products are low. Energy consumption remains on a 2010 level, and wood prices are stable. The federal state commits itself only to rather low emission reduction, but energy policy pushes new priorities in energy efficiency and climate protection.

Regional centres
Global development is characterised by an increasing focus on self-reliance and preservation of local identities and climate change according to the A2 scenario of the IPCC*. In Switzerland economic growth is moderate, and natural resource management is exploitive. As road and rail networks are improved, the accessibility of remote and mountain regions increases strongly within Switzerland, and in combination with rather loose spatial planning policy, this encourages rather exploitive tourism. Regional centres also within mountain regions grow, and there is a revival of mountain regions. Environmental awareness is generally low, and efforts in nature conservation are reduced. Swiss agricultural markets are protected, and innovation in agriculture is low. Mainly regionally produced goods are consumed, and end-user prices for agricultural products increase considerably. Energy consumption rises due to the lack of innovative technology, and wood prices are stable. The federal state commits itself to rather low emission reduction, and energy policy follows business-as-usual.

Green Growth
Global development is characterised by an emphasis on global solutions to economic, social, and environmental sustainability and climate change according to the B1 scenario of the IPCC*. In Switzerland economic growth is high with an increasing focus on service and information economies, and natural resource management can be sustainable. The accessibility of remote and mountain regions increases moderately within Switzerland, and spatial planning policy is restrictive. Tourism becomes more regionally rooted and sustainable. The mountain regions are popular as retreats where many people regularly spend their weekends. Environmental awareness builds on technological solutions, and efforts in nature conservation are extended. The Swiss agricultural policy promotes “green” production, and technological innovation in agriculture is high. The consumption of organically grown goods from all over the world is high, and end-user prices for agricultural products increase moderately. Energy consumption is stable, and due to a rising consumption in bio fuel, wood prices increase, too. The federal state commits itself to high emission reduction, and energy policy pushes new priorities in energy efficiency and climate protection.

Local Sustainability
Global development is characterised by increasing focus on local solutions to economic, social, and environmental sustainability and climate change according to the B2 scenario of the IPCC*. In Switzerland economic growth is moderate, and natural resource management is sustainable. The accessibility of remote and mountain regions remains stable within Switzerland and spatial planning policy is restrictive. Tourism becomes more regionally rooted and sustainable. Regional centres also within mountain regions grow and there is a revival of mountain regions. Environmental awareness promotes low-tech solutions, and efforts in nature conservation are extended. The Swiss agricultural policy promotes “green” production, but technological innovation is low. Mainly regionally produced goods are consumed, and end-user prices for agricultural products increase considerably. Energy consumption is stable, and due to an increase in bio fuel, wood prices increase, too. The federal state commits itself to rather high emission reduction, and energy policy follows the aim of a 2000-Watt society.
*See Table 3 for details on climate change.

complexity within the investigated system for expert judgements, which is typical for Formative Scenario Analysis and other mathematically based methods of scenario construction [e.g. 27]. Such a dissection of the investigated system can be a great advantage in highly complex systems where the systematic-qualitative approach might produce oversimplified stereotypes not entirely consistent in their logic. At the same time, this degree of formality can be at the expense of flexibility, deliberate inconsistencies, and incorporation of new emergent factors, which are valid options within the systematic-qualitative scenario development. This is true not only for an independent scenario development process, but also for trans-scale processes aiming to develop "coherent" [according to 14] scenarios from larger-scale source scenarios, as in our study.

4.3. Identification of inconsistencies in Formative Scenario Analysis

Closely related to that is the clear identification of possible inconsistencies in our thinking about the future, which is one of the important investigative advantages of the method. These inconsistencies are analytically interesting and socially instructive. In our case the four focus scenarios appear internally consistent at first sight, and it was not until the analysis of single ratings within the consistency matrix that potential conflicts became apparent. In our case, it is the "Green Growth" scenario which was the most controversial. Although the generally high environmental awareness matches well with the "Amenity Migration" and similarly with the "Strict Spatial Planning", the combinations of both indicate likely conflicts. One reason is that "Strict Spatial Planning" implies few and careful expansion of developed areas entailing rather intense utilisation density for the sake of minimal area impacted [43]. In reality, however, strict spatial planning slows down population increase and amenity migration [44]. This conflict is also reflected by the ratings of the combination of these two future levels. It is the only combination rated with a "strong conflict" (−2) occurring in the optimisation-based selection of feasible scenarios, and only indirect rating combinations lead to its appearance in the automated selection. A similar case in the same scenario is the combination of "Amenity Migration" and "Expansion of protected areas for nature protection" (rated with a "conflict", −1). It might be consistent that the general agreement on environmental awareness would enhance the efforts in protection, but an increase in "Amenity Migration" into the mountain regions might undermine these efforts. Still, it is reasonable not to reject the "Green Growth" scenario A) due to the likely growing importance of amenity migration for some Swiss mountain regions within daily or weekly commuting distance to the urban centres, and B) because it indicates where actual constraints between environmental-friendly and highly mobile, urban lifestyles might indeed be.

4.4. Overcoming two axes

As mentioned in the introduction a range of explorative scenarios has already been developed with relevance to ecosystem service management at the global, continental, national, and regional level [1,2,19–22,40,45]. Most of these systematic-qualitative scenarios use two key development dimensions to structure the scenario development why it has often been referred to as two-axes approach. For instance, for the SRES scenarios these two axes include one contrasting globalisation to regionalisation and another one contrasting economic versus sustainable development. Building strictly on the consistency ratings of future levels, Formative Scenario Analysis is here less ambiguous and more open towards unexpected scenarios that would not necessarily fit a two-axes approach [25]. Although less flexible in many other ways, this can be considered an advantage of the Formative Scenario Analysis. In our case of producing scenarios nested in the SRES scenarios and with a strong dominance of the impact factor "Global Trends", the two SRES axes have indirectly entered the logic of the set of focus scenarios. But they were combined in a different way: while economic growth and environmentalism were considered opposing directions of the same axis in the SRES scenarios, they occur within the same scenario in our results, i.e. these two development directions are not considered to exclude each other. Here, a shift in thinking since the late 1990s allows for the possibility that environment and climate protection might occur in conjunction with the generation of wealth, at least in highly developed countries through the development of innovative, highly advanced technology (depicted in the "Green Growth" scenario).

4.5. Role of expert judgement and procedure

There remain many similarities between formal and systematic-qualitative approaches to scenario development. The system definition, namely the collection of drivers (referred to as "impact factors" in the case of Formative Scenario Analysis) and the cross-rating of interaction between these drivers (in the "impact matrix" in the case of Formative Scenario Analysis) is crucial to both methods (see Fig. 2). In Formative Scenario Analysis, the next step is the definition of future levels and the rating of their consistency (in the "consistency matrix"). Systematic-qualitative scenario development, in contrast, identifies the two key dimensions of uncertainties and draws the development of the individual remaining drivers logically consistent along these dimensions in informal, based on intense discussions about consistencies and degree of separation between scenarios among the scenario development team.

Advantages are apparent in both approaches. Formative Scenario Analysis ensures the logic by combining the consistency ratings of each pair of future levels, but lacks the ability to adapt the number and the specification of future levels to optimise them for the final set of scenarios. Starting off from the big picture (i.e. development of the systems along two axes of key uncertainties), the systematic-qualitative approach is highly adaptive in this regard and, if developed with some experience and creativity, can hold valuable details and deliberate inconsistencies to the source scenarios.

The strong dependency on expert judgements, and associated susceptibility to personal judgement [as discussed in 26], exists also in Formative Scenario Analysis. Definitions of future states and their ratings are the result of long debates and possible iterative procedure, but the formative approach offers important advantage in ensuring a well-structured procedure that ensures a well-documented and reproducible process [17]. Furthermore, the discourse-based definition of future-states and the subsequent pair-wise rating of consistency break down the overall picture to an extent that over-simplification and strongly biased stereotypes through personal judgement are less likely to become dominant features in the resulting scenario.

Formative Scenario Analysis has been described as a sequential technique [33], however, the procedure we followed was highly iterative, similar to the experience in [29]. The iterative nature of this procedure contributed to greater interdisciplinary interaction and system understanding. During the course of analysis, the list of impact factors, their definitions and future levels had to be re-thought several times. For

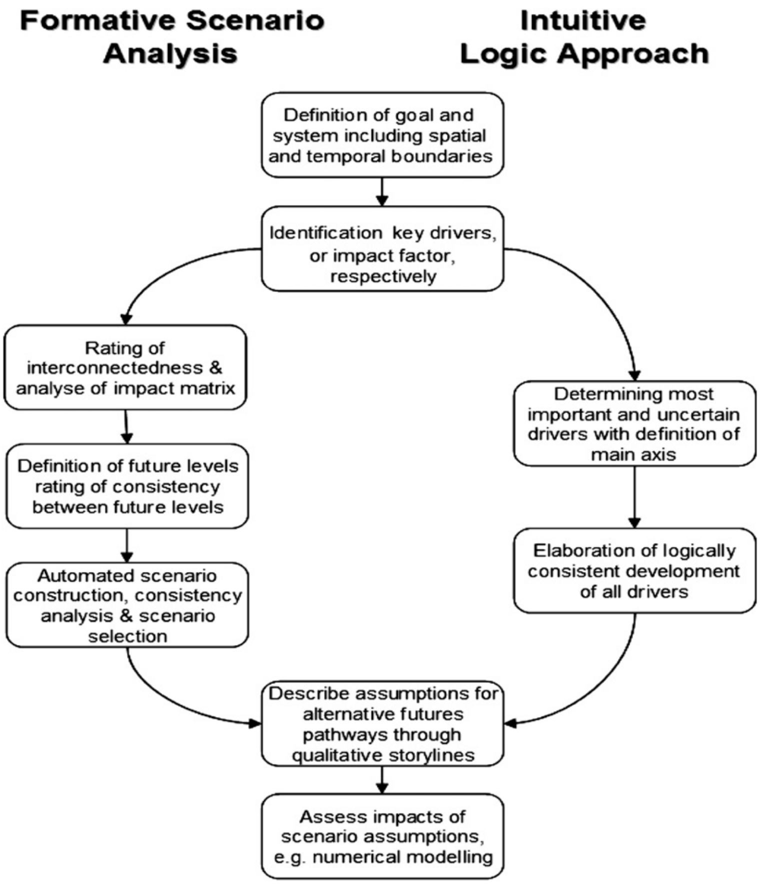

Fig. 2. Comparison of Formative Scenario Analysis [25] and scenario development based on the systematic-qualitative approach [23].

instance, it became obvious with the first consistency analysis that some consistencies were still rated on the basis of differing reasoning and needed re-thinking, i.e. re-phrasing of specific impact factors and future levels (referring to iterations between Step 4 and 5 in the Methods section). This iterative process is typical for scenario development. Independent of the more or less formative nature of the method chosen, scenario development can bring several collaborating colleagues with different disciplinary background together, and is a helpful process to build common ground for interdisciplinary research.

4.6. Meaning for ecosystem service management in Swiss mountain regions

What are the important factors for future ecosystem service management in Switzerland and how might they develop with respect to the given framing scenarios? The future management of ecosystem service in Swiss mountain regions is assumed to be strongly driven by both changes in provision due to climate change and environmental degradation, and socio-demographic driven changes in demand. Both aspects are directly covered in several of the impact factors accounted for in the analysis. Migration patterns within Switzerland, accessibility, tourism and the overall population development provide indication for the demand on ecosystem services. Climate and land-use related impacts of agriculture, spatial planning, nature conservation and natural resource management affect the provision of ecosystem services. The third type of impact factors refers to the willingness and ability to manage ecosystem services sustainably, and includes public attitudes towards the environment (reflected in the impact factors "Environmental Awareness", "Nature Conservation" and the "Consumption Patterns") and financial means ("Economic Growth").

It becomes apparent that some future levels seem to be partly contradictory to the global development as represented in the SRES scenarios (Box 1). One example is the price for agricultural commodities. Exploitive resource management and population growth (as stated in the SRES scenario A1, see Box 1) are important driving forces for increasing agricultural commodity prices on a global level [46]. Switzerland, however, shows a high level of political support for state intervention into the agricultural sector, and agricultural commodity prices at farm gate are on average 40% higher than world market prices [47]. Thus, we assume that national agricultural policy is the main driver for the development of end-users' commodity prices in Switzerland as long as economic wealth allows for it (which SRES scenario A1 does, see again Box 1). As a consequence, these prices decrease in our scenario "Growth & Convergence" even though some global driving forces point in a different direction.

When comparing with the spatial development scenarios of Switzerland [45], parallels in the future distribution of population within Switzerland become obvious. An important difference, however, is that Wissen et al. [44] assume an expansion of protected areas only under a decrease of population in mountain regions and a concentration of tourism to few Alpine tourism centres, while the MOUNTLAND focus scenarios propose an expansion of nature conservation independent of the demographic development in mountain regions. The underlying assumption implies that development, and constant or even increasing population can occur in mountain regions while agriculture and forestry might still undergo fundamental change over the coming decades and leave enough space for nature conservation.

5. Conclusions

Formative Scenario Analysis proved an appropriate technique to systematically deduce a set of formally consistent focus scenarios that are in line with a pre-defined set of scenarios, but target a different context and spatial level. The integration of a "Global Trends" variable proved helpful to develop scenarios consistent with SRES emission scenarios, and thus with the climate input data used in regional case studies. Thes technique will also be a valid option for independently downscaling coherent scenarios from the up-coming "Shared Socioeconomic Pathways" (SSPs) [2], as they are recently being developed in the form of socio-economic narratives and numbers for the upcoming Fifth Assessment Report AR5 of the IPCC.

Building on the mathematical evaluation of experts' rating of the consistency between future states of important drivers, the method can provide insight in contradictory societal expectations into the future, and, thus, has analytical power. In addition, the method allows for an open number of scenarios in the final selection and the main directions of future pathways do not need to be set in advance. Compared to systematic-qualitative scenario analysis, however, the development of single drivers within the scenario context is less flexible due to the fixed choices of future states for each driver, and the strong focus on consistency might exclude important combinations of future levels and lead to more moderate scenarios. Despite the formalism of the approach, there are still strong similarities between Formative Scenario Analysis and the systematic-qualitative scenario approach, namely the role of expert judgement in selecting drivers (i.e. impact factors) and future states (i.e. level), and then, also fundamentally important, their rating.

Finally, the final set of scenarios provides four coherent development pathways that reflect key uncertainties for future ecosystem service management in Swiss mountain regions. The scenarios give a comprehensive view on possible national level conditions for ecosystem service management and landscape management in Swiss mountain regions for 2050. With "Growth & Convergence", "Regional Centres", "Green Growth" and "Local Sustainability" they include the dimensions of economic growth, liberalisation, regionalisation and governance towards environmental protection and provide a solid boundary conditions for modelling and further scenarios development within such regions.

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Appendix A. Supplementary data

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