Adapting to climate and socio-economic land-use changes - the inter- and transdisciplinary research project MOUNTLAND

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Abstract. *The importance of goods and services provided by mountainous areas increases rapidly as the number of people depending on them grows. Yet, these ecosystems are fragile and vulnerable to rapid climate and socio-economic driven land-use changes. In order to identify adaptation strategies for sustainable development of mountainous landscapes, both supply and demand for ecosystem services under future scenarios needs to be assessed. Such task needs highly inter- and transdisciplinary research approaches. In this contribution, we present the inter- and transdisciplinary research project MOUNTLAND in which ecosystem functioning and management in mountain regions under climate and socio-economic changes are analyzed. We focus on introducing the core of the project - an economic land-use model linked to dynamic land-cover change models, which allows showing how land-users make ecosystem services' trade-offs under different normative scenarios. Opportunity costs for the provision of ecosystem services in a given landscape are presented in a spatially explicit manner. We discuss advantages and limitations of such an approach with respect to its value for suggesting adaptive landscape management practices.*

Keywords:, Inter- and transdisciplinary Research, Economic land-use model, Ecosystem Goods and Services, Mountainous ecosystems.

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PAPER PRESENTED AT THE

2ND INTERNATIONAL CONFERENCE ON LANDSCAPE ECONOMICS

JULY 4-6, 2011 PADUA/ITALY

www.landscapeeconomics.org

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1 Introduction

Landscape scientists and practitioners underline the importance of a holistic perspective and integrative approaches in the debate about sustainable development (Musacchio, 2009). Thus, inter- and transdisciplinary research plays a key role in landscape science (Wu, 2006; Pauleit et al., 2010; Musacchio, 2009; Tress et al., 2001; Tress et Tress, 2001; Naveh, 2001). Even though, inter- and transdisciplinary research poses a challenge due to (among else) the lack of common terminology across disciplines and limited resources with respect to time and funding (Tress et al., 2005; Tress et al., 2007; Fry, 2001) more holistic research in the assessment of ecosystem services are needed (Müller et al., 2010).

Modeling plays a key role in integrating knowledge across spatial scales, time and disciplines (Brouwer et van Ittersum, 2010; Nautiyal et al., 2010; Claessens et al., 2009; Agarwal et al., 2002). Integrated models of the land system can take different specifications (Schaldach et Priess, 2008; Agarwal et al., 2002) and the technique of integration in inter- and transdisciplinary research ranges from agent-based models (Gibon et al., 2010; Acevedo et al. 2008, Manson et Evans 2007) to coupling of different models (Waldhardt et al., 2010; Verburg et Overmars, 2009; Claessens et al., 2009), and Bayesian probabilistic approaches (Kragt et al., 2011). This research has however shown that human and natural systems are complex with respect to spatial as well as time scales and organizational units (Liu et al., 2007). According to Liu et al. (2007), case studies on coupled human and natural systems should I) address complex interactions and feedback effects, II) bring together an interdisciplinary study team which III) integrates various tools and techniques from ecological and social sciences and IV) integrate dynamic effects in their research. The authors conclude that it is critical to move beyond existing approaches and more comprehensive research portfolios are necessary. In this context, the consideration of climate and land-use change interactions is crucial (Verburg et Overmars, 2009). In addition, integrated approaches in which models and scenarios are developed in close interaction with stakeholders still remain a challenge (Houet et al., 2010).

In this article we present an inter- and transdisciplinary research project addressing the provision of ecosystem services in the context of climate and land-use changes in mountainous regions (MOUNTLAND). The research project focuses on three case study regions in the Swiss Alps. Based on an integrative approach, a broad portfolio of methods from economics, political, social and natural sciences are combined in order to develop adapted land-use practices and innovative policy solutions for mountain regions. The core element of the project is the economic land-use model ALUAM (Alpine Land-use Allocation Model). This spatially explicit land-use model integrates information from the different disciplines on a landscape scale. Based on normative future scenarios, trade-offs between different ecosystem goods and services are calculated. As a result, opportunity costs for the provision of a set of ecosystem services in a given landscape are presented. The project adds inter- and transdisciplinary knowledge to the existing research taking into account both land-use and climate change simultaneously and explicitly considering feedback effects from changing socio-economic and political conditions.

In Section 2, we provide a summary of the MOUNTLAND project. In Section 3, an economic land-use model and preliminary results are presented. Results are discussed with respect to inter- and transdisciplinary research as well as landscape economics in Section 4. Section 5 concludes.

2 The inter- and transdisciplinary research project MOUNTLAND

2.1 Goals of MOUNTLAND

Mountainous ecosystems provide a variety of important goods and services to humanity such as food and fiber production, high biodiversity,, natural hazard protection, CO_2 sequestration which guarantee the fulfillment of different information functions (Millennium Ecosystem Assessment, 2005). These ecosystems, however, are highly sensitive to both climatic and land-use changes (Bugmann et al., 2007). As a consequence of climate and land-use change, the provision of the above mentioned ecosystem goods and services might be altered (Gonzalez et al., 2010; Schröter et al., 2005). Agriculture, for instance, faces the challenge of intensified production on fertile soils, which leads to negative environmental consequences (Stöcklin et al., 2007) while at the same time marginal areas are abandoned (Gellrich et Zimmermann, 2007). In addition, agricultural production in Switzerland is highly dependent on subsidies. Despite increased prices, forestry production also struggles with low profitability (Gotsch et al., 2004). Moreover, primary production of agriculture and forestry is confronted with an increased societal demand for public goods and services (FAO, 2007). These requirements of the different social actors with respect to mountainous landscapes should be increasingly taken into account in private as well as public decision-making (Lehmann et Messerli, 2007).

Considering this background, the goal of MOUNTLAND is to contribute to the development of adapted land-use practices and innovative policy solutions for mountain regions that (1) warrant the life-supporting services required for sustainable development, (2) are economically and ecologically efficient, and (3) socially and institutionally feasible. An integrative approach is applied combining methods of economics, political and natural sciences to analyze ecosystem functioning and management in mountain regions under climate and socio-economic changes. Thus, the challenges of a sustainable landscape management are analyzed with a holistic perspective. In addition to the combined assessment of climate and land-use changes, MOUNTLAND applies an innovative approach by an integrative collaboration of different disciplines from the beginning of the project onward. Thus, our research is not only a cascade of different research findings but allows for explicit consideration of feedback effects from changing socio-economic and political conditions to land use and adaptation to climate, an important challenge in interdisciplinary research (Steffen, 2009). In addition, the choice of the methods, e.g. formative scenario analysis or network analysis results in a strong collaboration with residents and local decision makers. As expected from landscape sciences, the MOUNTLAND approach results in a truly inter- and transdisciplinary research project.

The MOUNTLAND project applies this research approach to three different Swiss Alpine regions. These are situated in the Jura (pasture-woodland ecosystems), in the Central Wallis (drought-sensitive inner Alpine ecosystems), and in Davos (temperature sensitive high Alpine ecosystems). The three regions differ in terms of their expected sensitivity to climate change, in terms of the relevance of different ecosystem goods and services and in terms of the relevance of different sectoral and cross-sectoral policies.

2.2 Conceptual framework of MOUNTLAND

Figure 1 represents the conceptual background and the methodological approaches of the MOUNTLAND project which is structured in three tasks.

Task 1 consists of ecological research including field investigations, experiments and modeling (dark grey shapes in Figure 1). Two different research approaches can be distinguished in this task. Firstly, ecological field experiments add specific knowledge on the effects of climate change on the functioning of the ecosystems in mountainous regions. For example, the transplantation of monolith soil turfs and herbaceous vegetation from Col du Marchairuz (VD) to lower altitudes investigates the effect of several levels of climate warming and reduced precipitation intensities interacting with different land-use practices typical for the Swiss Jura Mountains (Gavazov, 2010). In Davos, knowledge from the long term experiment at the tree line of Stillberg enters the MOUNTLAND project (Martin et al., 2010) and in the case study region Valais, different drought experiments investigate the germination, growth and mortality of different tree species (Dobbertin et al., 2010; Brunner et al., 2009; Eilmann et al., 2009). These experimental findings are used to improve existing mechanistic forest models in the corresponding area (Gillet, 2008; Schumacher et Bugmann, 2006; Lischke et al., 2006). Thus, interdisciplinary knowledge from natural scientists is modeled and upscaled to the regional level in order to quantify changes in ecosystem services in a spatially explicit manner.

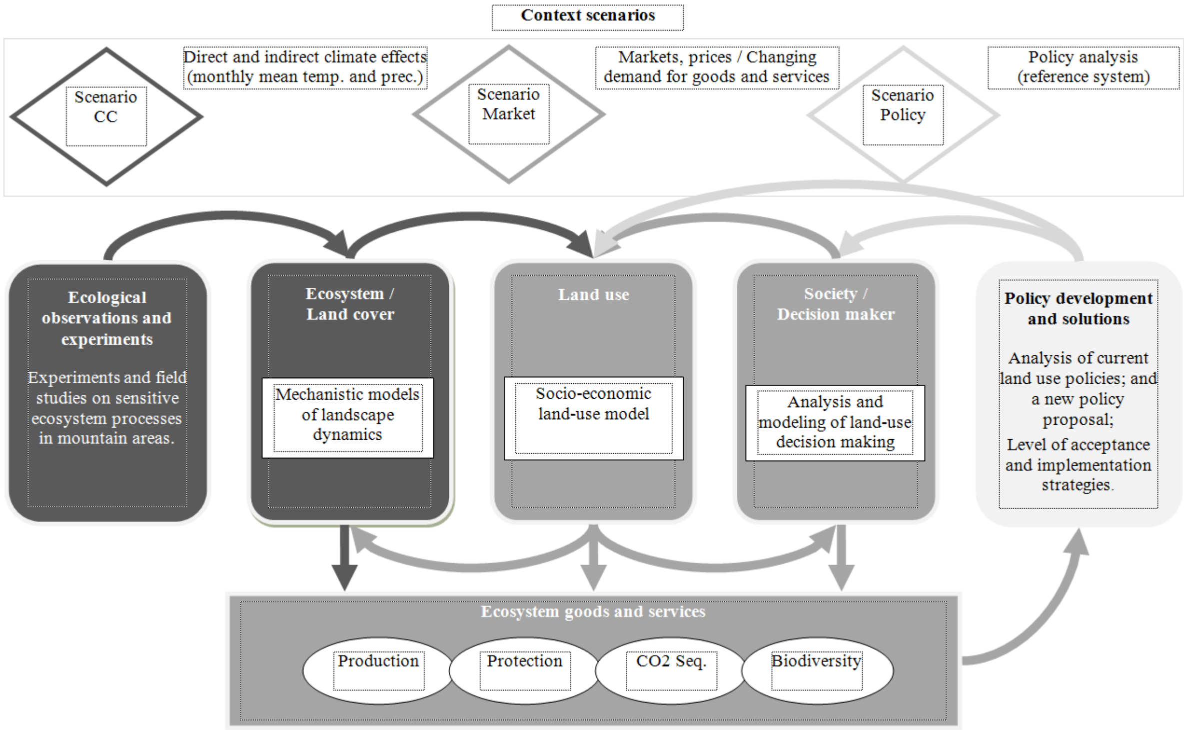

Figure 1: Workflow and research methods of different tasks in MOUNTLAND (Source: adapted from Koellner, 2009).

Task 2 (grey shapes in Figure 1) addresses socio-economic issues also from two different perspectives. On the one hand, the decision-making of local actors is analyzed using agent-based modeling techniques. The basis for the latter is provided by local scenarios which are developed in strong collaboration with residents and policy makers in the case study region (Braendle et al., 2010). In addition, an economic optimization model is constructed which represents the competition between agricultural and forest land-use in the different scenarios and provides information on ecosystem services changes in all the three case study regions (Briner et al., 2010). The model results show the trade- offs between economic gains from primary production and the provision of ecosystem services under climate change in the different regions. In this article, we focus on the description of the first results from this model because it integrates the information from the task 1 via the forest models and from task 3 which focuses on policy issues.

Task 3 (light grey shapes in Figure 1) focuses on the political aspects of the provision of mountain ecosystem services. In this task, current policies addressing climate and land-use changes are analyzed which generate knowledge about the future implementation of sustainable management practices. In a first step, the interactions of local, regional and national actors are identified using network analysis (Ingold et al., 2010). In parallel, a policy-oriented indicator system for ecosystem services is developed. These indicators refer to current goals on different levels of the administration in Switzerland. Moreover, the policy task proposes normative policies with respect to sustainable ecosystem services management for the different landscapes. These policies will take into account the specific implementation paths across the different actors in the case study regions and asses the acceptance of ecosystem services policies.

An iterative procedure allows for a comprehensively combination of the three different tasks. Starting point is the formulation of context scenarios for the three case study regions based on the formative scenario approach by Scholz und Tietje (2002). In these scenarios, consequences of global change (climate, markets, policies) are down-scaled to our case study regions and summarized by storylines (Walz et al., 2007).

These storylines provide the basis for a model-based analysis of land-use decision-making in the socio-economic task of MOUNTLAND. Modeling results from the first task add important information to the economic models . The combination of ecological and economic modeling approaches shows changes in ecosystem services provision for the different landscapes. Based on the different scenarios, trade-offs between the provision of different ecosystem goods and services can be quantified. At the same time, the policy task provides information on how different policies are implemented and they elaborate normative indicators for the evaluation and valuation of the different ecosystem services. These policy indicators are then used to evaluate the different outcomes of the scenarios. If the modeling outcome shows an underscore of the corresponding indicator, a policy change is proposed which re-enters the system of models. This procedure permits the assessment of feedback effects between the policy, economic and climate changes.

For the purpose of this article, however, the following constraint has to be explicit: societal demand is not considered using economic valuation techniques. Instead, policy indicators are used to assess the societal performance of the modeling results. The valuation of the ecosystem results from the calculation of opportunity costs under given policy constraints in the economic model. The underlying assumption is that societal demand is represented by these normative policy indicators. This may be seen as limitation of this research approach. However, the idea of this article is to show how the opportunity cost approach in economics can integrate information from different disciplines. Knowing that the opportunity cost approach in programming approaches has many drawbacks (Price, 1978), this clearly results in a non-exhaustive and indirect valuation of ecosystems.

3 Economic land allocation model ALUAM

3.1 Goals and characteristics of ALUAM

The core of our conceptual framework is a normative mathematical programming model called ALUAM (Alpine Land-Use Allocation Model). The motivation behind normative mathematical programming models is straightforward: these models are based on a sound theory (neoclassical economics). In this theory, economic agents are profit optimizers. Combined with limited resources, represented by model restrictions, these normative model approaches incorporate the fundamental economic problem: making the best out of limited resources (Buysse et al., 2007).

In order to assess changes in the provision of ecosystem goods and services, the goal of ALUAM is to simulate normative future land-use on a fine resolution in an economic framework. Results of specialized ecological models, socio-economic agent-based models as well as datasets containing (local) market and policy parameters provided by different tasks of the project are integrated into ALUAM. Thus, ALUAM is an important integrative part of the inter- and transdisciplinary research project MOUNTLAND.

The integration process is challenging in two ways (Verburg, 2006; Agarwal et al., 2002). Firstly, ALUAM has to address different scales. Whereas data for ecological modeling is needed on a very fine spatial scale and processes are bottom up driven (Verburg et al., 2009), economic driving forces influence land-use on a coarser resolution, e.g. on the farm- or regional level (Umstätter, 1999).Thus, they affect land-use change from a top down perspective (Verburg et al., 2010). Secondly, ALUAM faces different time scales. This problem is caused by the need to integrate agricultural- and forest land-use into one model. While decisions in forestry are made with a time horizon of at least decades, in agriculture they are made yearly. In forestry the effect of management changes may be seen only in the long run (60-80 years). In contrast, a change in agricultural management may influence ecosystem services provision in the short run.

To overcome these challenges, ALUAM is characterized by a

- Normative, linear programming approach since these models offer the possibility to link economic with ecological and biophysical elements (Buysse et al., 2007);
- Modular design which offers a straightforward structure suitable for the integration of different sets of data;
- Spatially explicit modeling design including a GIS interface in order to combine data from different sources and scales; and
- One-dimensional goal function (profit maximization) which offers the possibility to bridge time scales based on a sound theoretical background.

A normative perspective implies that the scenarios have the goal of generating desirable futures that are plausibly but not necessarily assuredly achievable (Nassauer et Corry, 2004). The purpose of these scenarios is close to what Nassauer et Opdam (2008) define as design in landscape change which can be a shared basis for scientific and societal assessment of landscape change. The clear structure of the model combined with a rational economic framework, should facilitate the communication of the model results within the MOUNTLAND research network as well as with stakeholders outside the scientific community.

We are aware that modeling with LP has two specific drawbacks. 1)The validity of the results is dependent on the model design and the reliability of the input-data. Simulations can be wrong if the model is based on an unsuitable design or false data (Wiborg et al., 2005; Hobbs, 1990). Thus, to receive proper results it is necessary to calibrate and validate the model exactly (Zander et al., 2008). ALUAM was validated simulating land-use ex-post and comparing the results with statistical data. The results of this validation process are satisfactory and can be found in the Appendix. 2) The simple form of the model may be an advantage in the elaboration and the communication of the model. However, simulation of future land-use changes can be incorrect as the model does neither consider uncertainty nor does it consider all factors influencing the decision-making process of land-users. Decision-making of human beings is, other than the goal function of an LP, multidimensional considering different types of utilities.

These drawbacks are addressed in two ways: ALUAM explicitly considers non-economic driving forces in the local decision-making by integrating results of an agent-based model (Braendle et al., 2010). The findings of this model which are based on scenarios expressed by local stakeholders provide restrictions for the normative programming model. With respect to uncertainty, we apply sensitivity analyses.

3.2 Interdisciplinary Model Components

For the design of ALUAM data from different tasks of the MOUNTLAND-project as well as from different external data sources was integrated in the model. The land-use activities are designed on field level using spatial explicit data sets. Thus main input data are results derived from two ecological models: a forest-simulation and a crop-yield model.

Forest-simulation model LandClim

Timber harvest, and forest derived ecosystem good and services were simulated using the forest simulation model LandClim (Schumacher et al., 2004). LandClim is a spatially explicit process-based model that incorporates competition-driven forest dynamics and landscape-level disturbances to simulate forest dynamics for the different landscapes. LandClim simulates forest growth in 25 by 25 m cells using simplified versions of tree recruitment, growth and competition processes that are commonly included in forest gap models (Bugmann, 2001).

Crop-yield model

For the calculation of the crop-yields FAO – Food and Agriculture Organization of the UN - data on optimal and absolute crop growing conditions were used. A relative crop yield curve is fit for both temperature and precipitation values using an incomplete beta distribution. The relative yield curves ranged from values of zero where the crop can't grow, to a value of 1 when temperature and precipitation values produce the highest yield. These species specific crop yield curves were then used to calculate the relative yield for regionally relevant crops.

Based on spatially explicit data such as climatic parameters (monthly temperature and precipitation), these models provide data about the potential yield of the different land-use activities. This ability to consider climate data makes these models especially important for the MOUNTLAND project because they enable the simulation of potential yields for different climate scenarios. Together with other spatially explicit data, potential yield is used to characterize every single parcel. The other spatially explicit data contains for example information about the topographic or soil conditions of each parcel. The dataset assigned to each parcel is shown in Table 1. Inside ALUAM all data is combined to design different land-use activities.

To link land-use and livestock activities with economic parameters as well as for policy and legal restrictions data from different policy and market scenarios have to be integrated into the ALUAM model.

Parameter	Source	Comment
Potential forest yield	Forest-simulation model	Calculations based on climate, soil suitability and topography
Potential crop yield	Crop-yield model	Calculations based on spatial explicit climate data.
Elevation/Slope	Swisstopo, 2005	Digital elevation model.
Soil suitability	Federal office for agriculture (BLW), 2000	Digital soil suitability map
Remoteness	Federal office for statistics (BFS), 2000	Raster map with a resolution of 1:25'000, Calculations in ArcGis.
Administrative zones	BLW, 1997	Digital map of the administrative zones for agriculture. Base for calculation of direct payments

Table 1: Spatial explicit data used for the design of the land-use activities

Scenarios

The climate scenarios used in this framework were derived from the Third Assessment Report of the the Intergovernmental Panel on Climate Change. These scenarios were combined with the global climate model HadCM3 (Mitchell et al., 2004) to receive climate data with a resolution of 10'. Using an anomaly method (Mitchell et al., 2005) climate data was downscaled on a local level to a resolution of 25m.

Our policy and market scenarios are based on IPCC scenarios, as one of the most recognized set of climate related future scenarios, and because these IPCC scenarios also build the basis of the input of climate data (Walz et al., 2010). However, the storylines of the IPCC scenarios needed to be downscaled to our study regions and expanded by further assumptions with respect to the management of ecosystem services in focus (Walz et al., 2010). For this process a formative scenario analysis has been applied.

The assessment presented in this article is based on the IPCC scenario A1FI. This scenario is characterized by a rapid economic growth as well as fast accumulation of greenhouse gases in atmosphere leading to high increase in temperature. The socio-economic indicators for this scenario predict a decline in prices for agricultural products. Input factors mainly become cheaper as well but because of the growth of economy labor costs will rise dramatically (Abildtrup et al., 2006).

Agent-based model

To anticipate subtle management decisions of actors on different levels of society a spatially explicit Bayesian Network approach is applied (Braendle et al., 2010). The Bayesian Networks representing the actors' influence spheres explore the likelihood for actors to adopt specific land-use or policy options with a major impact on ecosystem goods and services supply. The influence spheres are linked to parcels in GIS. Ecosystem goods and services considered include land abandonment or change of livestock systems. Influencing factors and their relative strength for different actor types were identified in a previous study on ecosystem goods and services through workshops, semi-structured interviews based on cognitive mapping and a survey on land use decision-making. Results of this model are implemented into ALUAM over additional constraints.

The output of ALUAM - detailed land-use maps as well as aggregated data about future land-use and ecosystem goods and services provision –will be inputs for the design of policy measures that deal with possible future problems. These measures will afterwards be tested on their economic efficiency by ALUAM again.

3.3 General structure of ALUAM

Figure 2 illustrates the specific construction of ALUAM. The combination of the land-use and livestock activities (I) is optimized in a way that the goal-function (II) is maximized. Different constraints (III) assure that restrictions (IV) on different levels are met. In ALUAM decision-making processes are modeled on the field, farm and regional level. On the field level decisions are made about the land-use activities. In making these decisions the quality of the field, e.g. soil quality or slope as well as the spatial location, i.e. the distance to the next farm restrict the availability of different activities on certain fields.

In mountainous regions a proper design of farm-level decisions is especially important as large parts of the land only can be used as grassland. For generating value grass has to be utilized by livestock and decisions about animal husbandry are made on the farm level. There are different flows between livestock and land-use. Therefore decisions on the field level are linked with livestock-activities over different balances, e.g. fodder or nutrient balances. If different spatial units are part of one farm these have to be summed up for calculating these balances. Some resources on a regional level are only available in a restricted amount and therefore balanced over the whole region. By calculating the different balances activities on a lower spatial level have to be summed for the calculation as well. On every level there are different political and legal restrictions that have to be considered. These restrictions represent for example laws preventing water pollution.

In the goal function of the model (II) the aggregated land rent is calculated. This indicator was chosen for optimization because it is an appropriate and useful approach to measure the potential economic performance of land use systems (van Kooten, 1993)

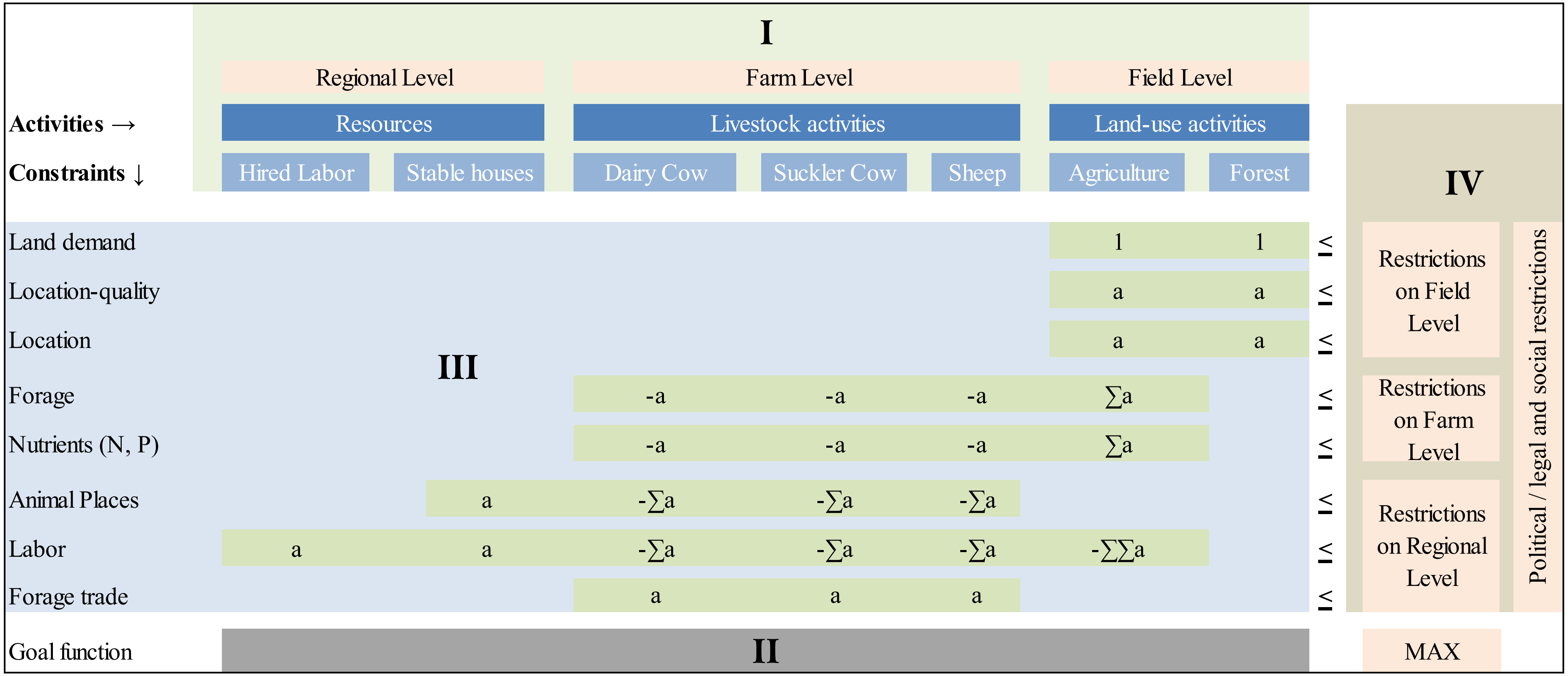

Figure 2: General structure of ALUAM: Expanded structure of a Linear Programming model; activities (I) are optimized in a way that goal function (II) is maximized. The consideration of different equations (III) guarantees that the restrictions (IV) are fulfilled. If restrictions are balanced over more than one decision-level activities of lower levels have to be summed up.

3.4 Preliminary results

3.4.1 Land-use changes

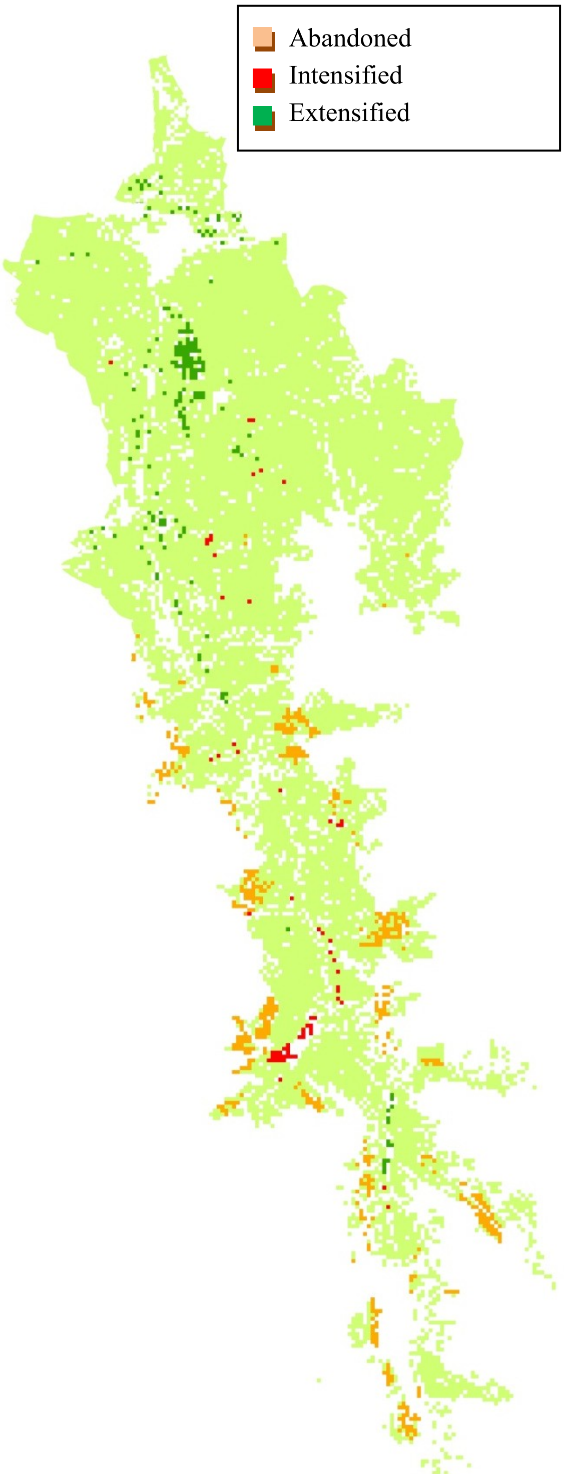

Figure 3: Land-use changes between 2000 and 2080 in the IPCC scenario A1FI

Preliminary results for one landscape show climate as well as socioeconomic impacts on land-use in our case study region Visp.

Figure 3 illustrates simulated land-use changes between the years 2000 and 2080. In this scenario, about 16% of the agricultural land is abandoned. Most of this land is located in remote areas on higher altitudes. Even with the impact of climate change on these high altitudes, yields are still relatively low in 2080. Thus, cultivation is not profitable anymore as the relation between input and output prices are influenced negatively in the corresponding economic scenario.

In addition to land abandonment, about 12% of the intensively used meadows are used less intensively. Simulations considering climate and socio-economic changes independently showed that socio-economic drivers are mainly responsible for this change in land use: Decreasing prices for agricultural products in combination with rising costs for production factors lead to an extensification of land-use. Most of the extensified fields are located on the slopes of the valleys where cultivation is rather labor intensive and therefore becomes expensive when opportunity costs rise.

Beside this process of extensification other parts of the region are used more intensively. These are mainly fields on the valley bottom that were used extensive in the year 2000 but where potential yields increased because of climate change. This increase made an intensive use of this parcels profitable.

These results are in line with other land-use change studies which show that intensification and extensification occur spatially explicit but in the same region and at the same time.

3.4.2 Provision of agricultural ecosystem goods and services

Land-use and climate changes also have an impact on the provision of different agricultural ecosystem goods and services. Table 2 shows selected ecosystem goods and services (first column), the indicator which is used to represent the corresponding goods and services in the model (second column), the percentage change with respect to the actual unit e.g. hectare or kilograms (third column), the policy goal of Swiss Federal Administration associated with the corresponding goods and services (fourth column) and the opportunity costs to reach the policy goals given climate and socio-economic changes until 2080 (last column).

We used the following indicators for the assessment of agricultural ecosystem goods and services: a) The share of extensively used meadows and mountain dry meadows for indicators of biodiversity conservation. These land-use type are especially rich in species diversity (Baumgärtner et Hartmann, 2007; Dullinger et al., 2006). Thus, they contribute substantially to species diversity in Switzerland. b) The proportion of land cultivated by agriculture is used as an indicator for open landscape. Landscape maintenance contributes to aesthetic beauty and intellectual stimulation thus cultural services in the ecosystem goods and services concept. c) Meat and milk production represent the provisioning functions.

Result show that for the year 2080 the contribution to biodiversity conservation is increased compared to the year 2000 without additional management restrictions (Table 2). Hence there are no opportunity costs associated with the goal of biodiversity conservation.

Ecosystem function	**Indicator for ecosystem goods and services**	**Change**	**Policy goal**	**Costs to reach policy goals**
Habitat	Share of agricultural land cultivated as extensive meadows	+2.7%	30% of agricultural land in the mountain areas ecologically valuable (Aeschbacher et al. 2008)	0 CHF
	Share of dry-meadows that is cultivated	+41%		0 CHF
Information	Landscape maintenance: Proportion of land cultivated by agriculture	-16.2%	100% of agricultural land are cultivated (BLW 2009)	7,06 Mio.CHF (-74%)
Provision	Meat production	+65%	No decrease in food production measured as energy production (BLW 2009)	0 CHF
	Milk production	-100%		391‘849 CHF (-4%)

Table 2: Change in the provision of agricultural ecosystem goods and services between 2000 and 2080 assuming IPCC-scenario A1FI. To keep provision on the level of the policy goal opportunity costs have to be accepted.

In contrast, landscape maintenance is influenced negatively in this scenario. The area managed by agriculture decreases by 16%. This large amount of abandoned land could influence scenic beauty negatively as people prefer a balanced mixture of agriculture and forest ecosystems (Hunziker et Kienast, 1999). Hence it is a goal of Swiss agricultural policy that any agricultural land is abandoned (BLW, 2009). To keep land-cultivation on the level of the year 2000 opportunity costs of 7 Millions CHF would have to be accepted. As only the achievement of the single goal was enforced by the model other goals as described in Table 2 can be affected in positive or negative way by this measure.

The different scenarios also have an impact on the provision of food. Our results show that farmers should focus on suckler cow breeding in order to optimize their profits. Milk production and sheep farming is ceased in this scenario. As a consequence, meat production increases by 65% and milk production decreases by 100%. If the Swiss public decides to keep milk production on the level of the year 2000 this will cause a decline in the aggregated land rent by 400 kCHF or 4% of the total agricultural income.

4 Discussion

The presented model ALUAM is designed for the projection of land-use change in agriculture and forestry under global change in mountainous regions. The integration of data from different sources (forestry simulation model, agent-based land-use decision-making, local scenarios) allows for a quantification of ecosystem services change for different landscapes. Based on these results, opportunity costs in the provision of specific ecosystem goods and services can be calculated.

Preliminary results for one landscape illustrate that our economic modeling approach provides a comprehensive tool in assigning monetary units to the provision of ecosystem services. The calculations show that, for instance, biodiversity conservation in agricultural areas must not be costly (in terms of opportunity costs) and that agricultural production and biodiversity can be provided in the same landscape despite climate and land-use change impacts. This can be interpreted as a win-win situation for the provision of different ecosystem goods and services such as biodiversity and food provision which is an important aspect in identifying sustainable management strategies (Naidoo et al., 2007, Naidoo et Iwamura, 2007). In contrast, the preservation of open space in Alpine landscapes exhibit high opportunity costs which ask for a more specific analysis of the societal demand in this specific region. In addition, spatial differences in the allocation of land-uses must be considered if policy measures are addressed. The abandonment of land, for instance, occurs in remote areas on higher altitudes. Thus, a unified policy measure for the whole region may be inefficient (Fraser et al., 2006; Antle et Stoorvogel, 2006).

However, opportunity costs represent but one (monetary) approach in valuing ecosystem goods and services. In addition to monetary terms, Müller et al. (2010) refer to the fact that ecosystem and landscape services can also be quantified in the unit of the actual service provision (e.g. m^2 of ecological compensation areas). They conclude that the choice of units depends on the research goals and should be selected with care (Müller et al., 2010). In this respect, ALUAM represents a model framework in which both levels can be addressed. Using an opportunity costs approach, actual and monetary units can be combined. In the current state, the demand for non-use values such as existence or option values is not considered in our results which can be seen as a drawback of our approach. However, the framework of the model easily allows for the integration of quantities of societal demand provided by other economic valuation methods. Non-use values of ecosystem services, for instance, can be integrated using contingent valuation methods in the study area and introduce corresponding restriction into the model (e.g. Waldhardt et al., 2010).

Moreover, the model will be able to elicit more trade-offs (or win-win situations) between different ecosystem services such as natural hazard protection, biodiversity conservation, CO_2 sequestration and food and wood production in order to get a more holistic perspective.

The quantification and valuation of such a diversity of different ecosystem goods and services is only possible because the programming approach offers the opportunity to interlink data and knowledge from different scientific disciplines and across time and scales, two important components of landscape economics . Such integrative approaches add important knowledge with respect to feedback effects and cross-scale interactions. Especially, the integration of biophysical components (experiments in Task 1) via the forest model into the economic programming model provides a basis for an in-depth analysis of ecosystem goods and services provision in a spatially explicit manner. Without this knowledge of the ecological process behind the service supply, it is difficult to quantify and map ecosystem goods and services (e.g. Kragt et al., 2011; Müller et al., 2010; Claessens et al., 2009).

The key in the integrative assessment of decisions influencing the provision of ecosystem goods and services is an effective use and integration of data sources (Müller et al., 2010). Linear programming models such as ALUAM can provide such information. The modular and straightforward structure of the model in combination with a rational economic background provides a solid basis for an optimal choice between different management options which is one of the main goals of the MOUNTLAND project. Thereby, the focus is less on a detailed representation of human decision-making but on a sound and comprehensive integration of data for different landscapes. As a consequence, the results of our optimization model must be interpreted as prescriptive but not descriptive statements. That is, our results state: 'in order to maximize profits, people should make the following decisions' (prescriptive) but not 'people will succeed in maximizing profits, because they will make the following decisions' (descriptive) (Sterman, 1991). Thus, our results refer to normative landscape scenarios which have particular potential for constructing more explicit, relevant relationships between the science of landscape ecology and policy (Nassauer et Corry, 2004).

The normative perspective differentiates ALUAM from agent-based models. These models have become the state-of-the-art in environmental modeling because of their ability to represent human decision-making in more detail (for a review: Heckbert et al., 2010; Le et al., 2008) and address also land-use change dynamics (Gibon et al., 2010; Acevedo et al., 2008; Manson et Evans, 2007; Parker et al., 2003). However, empirical calibration and validation is also a great challenge in these model types (Heckbert et al., 2010). The integration of different ecological and socio-economic environments with specific agents may result in a very specific model that cannot be easily transferred between regions. However, this is a major requirement in the MOUNTLAND context, since different study regions are analyzed. In addition, model results may be difficult to communicate since the rules for the different agents must be outlined and justified in each case. In contrast, optimization models can consider social and ecological aspects by using constraints.

As Tress et al. (2005) as well as Tress et al. (2007) show, two major barriers in inter- and transdisciplinary research are different academic traditions and the lack of common terminology. Rational economic behavior as the key-rule in the modeling framework of ALUAM makes the communication of the model results easier because the different tradition and terminology is made explicit. This does not mean that we do not consider non-economic driving forces in the decision-making. However, the corresponding factors are made explicit in the form of constraints and are not hidden in a complex decision rule within the agents. In addition, understanding the complexity of agent-based models is a very time consuming issue, which represents a third major barrier to successful interdisciplinary research projects (Tress et al., 2005; Tress et al., 2007). Moreover, ALUAM can also be used as a basis for visualizing tools (e.g. Wissen et al., 2007) and can contribute to the communication not only with stakeholders but also within the research project. This is important to overcome well known barriers to inter- and transdisciplinary research.

5 Conclusion

The MOUNTLAND project represents a good example of an inter- and transdisciplinary research project that integrates collaborative efforts across disciplines and between stakeholders. The economic land-use model ALUAM allows for taking into account the structures and processes of the ecosystems in the valuation of ecosystem goods and services for different landscapes. Moreover, the model provides a platform for the integration of different inter- and transdisciplinary data and knowledge on a common scale. This provides a basis for the communication of research results within the MOUNTLAND network and stakeholders outside the scientific community.

References

Abildtrup J., Audsley E., Fekete-Farkas M., Giupponi C., Gylling M., Rosato P. and Rounsevell M. (2006). Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. *Environmental Science and Policy*, 9: 101-15.

Acevedo M.F., Callicott J. B., Monticino M. et al. (2008). Models of natural and human dynamics in forest landscapes: Cross-site and cross-cultural synthesis. *Geoforum*, 39: 846–866.

Agarwal C., Green G.M., Grove J.M., Evans T.P. and Schweik C.M. (2002). A Review and Assessment of Land-Use Change Models.Dynamics of Space, Time, and Human Choice. CIPEC Collaborative Report Series No.1.

Antle J.M. and Stoorvogel J.J. (2006). Predicting the supply of ecosystem services from agriculture. *American Journal of Agricultural Economics*, 88:1174–1180.

BAFU and BLW (2008). Umweltziele Landwirtschaft. Hergeleitet aus bestehenden rechtlichen Grundlagen. Umwelt-Wissen Nr. 0820. Bundesamt für Umwelt, Bern.

Baumgärtner J. and Hartmann J. (2001). The design and implementation of sustainable plant diversity conservation program for alpine meadows and pastures. *Journal of Agricultural & Environmental Ethics*, 14: 67–83.

BLW (1997). Landwirtschaftliche Zonengrenzen. Federal office for agriculture, Bern (Switzerland).

BLW (2000). Digital soil-suitability maps. Federal office for agriculture, Bern (Switzerland).

Braendle J., Le Q.B., Koellner T. and Scholz, R.W. (2010). Modelling multi-level land use decisions with Bayesian networks. *Paper presented at the GLP Open Science Meeting "Land Systems, Global Change and Sustainablility", October 17-19 2010, Arizona, USA.*

Briner S., Zurbriggen N. and Huber R. (2010). Change of land-use under different climate and policy scenarios: A case study in the municipality of Davos. *Paper presented at the GLP Open Science Meeting, 17-19 October 2010 Arizona, USA*.

Brouwer F.M. and van Ittersum, M.K. (Eds.) (2010). Environmental and Agricultural Modelling: Integrated Approaches for Policy Impact Assessment. Springer, Berlin.

Brunner I., Graf-Pannatier E., Frey B., Rigling A., Landolt W. and Dobbertin M. (2009). Morphological and physiological responses of Scots pine fine roots to water supply in a climatic dry area in Switzerland. *Tree Physiology,* 29: 541-550.

Bugmann H. (2001). A review of forest gap models. *Climatic Change,* 51: 259–305.

Bugmann H., Gurung A.B., Ewert F., Haeberli W., Guisan A., Fagre D. and Kääb A. (2007). Modeling the Biophysical Impacts of Global Change in Mountain Biosphere Reserves. *Mountain Research and Development*, 27: 66-77.

Buysse J., Van Huylenbroeck G. and Lauwers L. (2007). Normative, positive and econometric mathematical programming as tools for incorporation of multifunctionality in agricultural policy modelling. *Agriculture, Ecosystems & Environment*, 120: 70-81.

Claessens L., Schoorl J.M., Verburg P.H., Geraedts L. and Veldkamp A. (2009). Modelling interactions and feedback mechanisms between land use change and landscape processes. *Agriculture, Ecosystems & Environement,* 129:157–170.

COE (2000). Council of Europe: The European Landscape Convention: Reference texts on landscape. URL: www.coe.int/t/e/cultural_co-operation/environment/landscape/. (January 2011).

Dobbertin M., Eilmann B., Bleuler P., Giuggiola A., Graf Pannatier E., Landolt W., Schleppi P. and Rigling A. (2010). Effect of irrigation on needle, shoot and stem growth in natural drought exposed Pinussylvestris forests, *Tree Physiology*, doi:10.1093/treephys/tpp123.

Dullinger S., Dirnböck T., Greimler J. and Grabherr G. (2006). A resampling approach for evaluating effects of pasture abandonment on subalpine plant species diversity. *Journal of Vegetation Science*, 14: 243–252.

Eilmann B., Zweifel R., Buchmann N., Fonti P. and Rigling A. (2009). Drought-induced adaptation of the xylem in Scots pine and pubescent oak. *Tree Physiology*, 29: 1011-1020.

FAO (2007). The state of food and agriculture: Paying farmers for environmental services. *FAO Agricultural Series,* No.38: 3-114.

Fraser E.D., Dougill A.J., Mabee W.E., Reed M. and McAlpine P. (2006). Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. *Journal of Environmental Management,* 78:114-127.

Fry G.L.A. (2001). Multifunctional landscapes—towards transdisciplinary research. *Landscape Urban Planning*, 57: 159–168.

Gavazov K. (2010). MOUNTLAND - successful experiment set up in the Jura Mountains. CCES Newsletter. URL: www.cces.ethz.ch/silva_ethz/ETH/sl/cces/cces/news/infos#2: (July 2010)

Gellrich M. and Zimmermann N.E. (2007). Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning*, 79: 65-76.

Gibon A., Sheeren D., Monteil C., Ladet S. and Balent G. (2010). Modelling and simulating change in reforesting mountain landscapes using a social-ecological framework. *Landscape Ecology*, 25: 267–285.

Gillet F. (2008). Modelling vegetation dynamics in heterogeneous pasture-woodland landscapes. *Ecological Modelling*, 217: 1–18.

Gonzalez P., Neilson R.P., Lenihan J.M. and Drapek R.J. (2010). Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography*, 19: 755–768.

Gotsch N., Flury C., Kreuzer M., Rieder P., Heinimann H.R., Mayer A.C. and Wettstein H-R. (2004). Land- und Forstwirtschaft im Alpenraum - Zukunft im Wandel. Synthesebericht des Polyprojektes 'PRIMALP - Nachhaltige Primärproduktion am Beispiel des Alpenraums' der ETH Zürich. Wissenschaftsverlag Vauk, Kiel.

Hobbs N.T. (1990). Diet selection by generalist herbivores: a test of the linear programming model. In: Hughes RN editors, Behavioural mechanisms of food selection (NATO ASI series, vol G 20). Springer, Berlin, Heidelberg, New York.

Houet T., Verburg P. and Loveland T., (2010). Monitoring and modelling landscape dynamics. *Landscape Ecology*, 25: 163–167.

Hunziker M. and Kienast, F. (1999). Potential impact of changing agricultural activities on scenic beauty – a prototypical technique for automated rapid assessment. *Landscape Ecology*, 14: 161–176.

Ingold K., Balsiger J. and Hirschi C. (2010). Climate change in mountain regions: how local communities adapt to extreme events. *Local Environment*, 15: 651-661.

Koellner T. (2009). Supply and Demand for Ecosystem Services in Mountainous Regions. *Alpine space – man and environment*, 7: 61-70.

Kragt M.E., Newham L.T.H., Bennett J. and Jakeman A.J. (2011). An integrated approach to linking economic valuation and catchment modelling. *Environmental Modelling & Software*, 26: 92-102.

Le Q.B., Park S.J., Vlek P.L.G. and Cremers A.B. (2008). Land-Use Dynamic Simulator (LUDAS): A multi-agent system model for simulating spatio-temporal dynamics of coupled human–landscape system. I. Structure and theoretical specification. *Ecological Informatics*, 3: 135-152.

Lehmann B. and Messerli P. (2007). The Swiss National Research Program "Landscapes and habitats of the Alpine Arc". *Revue de géographie alpine*, 95: 7-18.

Lischke H., Zimmermann N.E., Bolliger J., Rickebusch S. and Loffler T.J. (2006). TreeMig: A forest-landscape model for simulating spatio-temporal patterns from stand to landscape scale. *Ecological modelling*, 199: 409–420.

Liu J., Dietz T., Carpenter S.R. et al. (2007). Complexity of Coupled Human and Natural Systems. *Science*, 317: 1513-1516;

Manson, S.M. and Evans T. (2007). Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. *PNAS* 104: 20678–20683.

Martin M., Gavazov K., Körner C., Hattenschwiler S. and Rixen C. (2010). Reduced early growing season freezing resistance in alpine treeline plants under elevated atmospheric CO2. *Global Change Biology*, 16: 1057–1070.

MEA Millennium Ecosystem Assessment (2005). Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis, Island Press, Washington, DC.

Mitchell T. D., Carter R.C., Jones P.D., Hulme M. and New M. (2004). A comprehensive set of climate scenarios for Europe and the globe. Tyndall Centre Working Paper 55, Tyndall Centre for Climate Change Research, Norwich UK..

Mitchell T.D. and Jones PD. (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology*, 25: 693-712.

Müller F., de Groot R. and Willemen L. (2010). Ecosystem services at the landscape scale: the need for integrative approaches. *Landscape Online*, 23: 1-11.

Musacchio L.R. (2009). The ecology and culture of landscape sustainability: emerging knowledge and innovation in landscape research and practice. *Landscape Ecology,* 24: 989–992.

Naidoo R. and Iwamura T. (2007). Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. *Biological Conservation*, 140: 40–49.

Naidoo R., Balmford A., Costanza R. et al. (2007). Global mapping of ecosystem services and conservation priorities. PNAS July 15, 2008 vol. 105 no. 28 9495-9500.

Nassauer J.I. and Corry R.C. (2004). Using normative scenarios in landscape ecology. *Landscape Ecology* 19: 343-365.

Nassauer J.I. and Opdam P. (2008). Design in science: extending the landscape ecology paradigm. *Landscape Ecology*, 23: 633–644.

Nautiyal S., Rao K.S., Kaechele H. and Zander P. (2010). Conceptual model development for landscape management in the mountains of the Indian Himalayan region: an approach for sustainable socioecological development. *Landscape Online*, 18: 1-19.

Naveh Z. (2001). Ten major premises for a holistic conception of multifunctional landscapes. *Landscape and Urban Planning*, 57: 269–284.

Parker D., Manson S., Janssen M., Hoffmann M. and Deadman P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annuals of the Association of American Geographists,* 93: 314–337.

Pauleit S., Breuste J., Qureshi S. and Sauerwein M. (2010). Transformation of rural-urban cultural landscapes in Europe: Integrating approaches from ecological, socio-economic and planning perspectives. *Landscape Online*, 20: 1-10.

Price C. (1978). Landscape economics. The Macmillan Press LTD, London.

Schaldach R. and Priess J.A. (2008). Integrated Models of the Land System: A Review of Modelling Approaches on the Regional to Global Scale". URL: www.livingreviews.org/lrlr-2008-1 (March 2011).

Scholz R.W. and Tietje O. (2002). Embedded Case Study Methods: Integrating Quantitative And Qualitative Knowledge. Thousand Oaks, Sage.

Schröter D., Cramer W., Leemans R. et al. (2005). Ecosystem Service Supply and Vulnerability to Global Change in Europe. *Science*, 310: 1333-1337.

Schumacher S. and Bugmann H. (2006). The relative importance of climatic effects, wildfires and management for future forest landscape dynamics in the Swiss Alps. *Global Change Biology*, 12: 1435-1450.

Schumacher S., Bugmann H. and Mladenoff D.J. (2004). Improving the formulation of tree growth and succession in a spatially explicit landscape model. *Ecological Modelling,* 180: 175–194.

Schweizerische Bundesrat 2009: Weiterentwicklung des Direktzahlungssystems. Der Schweizerische Bundesrat, Bern (Switzerland)

Steffen W. (2009). Interdisciplinary research for managing ecosystem services. *PNAS,* 106: 1301-1302.

Sterman J.D. 1991. A skeptic's guide to computer models. In Grant L. editor, *Foresight and National Decisions*. University Press of America, Lanham.

Stöcklin J., Bosshard A., Klaus G., Rudmann-Maurer K. and Fischer, M. (2007). Landnutzung und biologische Vielfalt in den Alpen: Fakten, Perspektiven, Empfehlungen. Thematische Synthese zum Forschungsschwerpunkt II <Land- und Forstwirtschaft im alpinen Lebensraum>. Schweizerischer Nationalfonds, Bern.

Swisstopo (2000). Digitale Landeskarten der Schweiz im Rasterformat. Bundesamt für Landestopographie, Wabern (Switzerland).

Swisstopo (2005). DHM25, Das digitale Ho¨henmodell der Schweiz. Bundesamt für Landestopographie, Wabern (Switzerland).

Tress B. and Tress G. (2001). Captilising on multiplicity: a transdisciplinary systems approach to landscape research. *Landscape and Urban Planning*, 57: 143–157.

Tress B., Tress G., De´camps H. and d'Hausteserre AM. (2001). Bridging human and natural sciences in landscape research. *Landscape and Urban Planning*, 57: 137–141.

Tress B., Tress G. and Fry G. (2005). Researchers' experiences, positive and negative, in integrative landscape projects. *Environmental Management,* 36: 792–807.

Tress G., Tress B. and Fry G. (2007). Analysis of the barriers to integration in landscape research projects. *Land Use Policy*, 24: 374–385.

Umstätter J. (1999). Calibrating Regional Production Models using Positive Mathematical Programming. An Agro-Environmental Policy Analysis in Southwest Germany. Shaker Verlag, Aachen.

van Kooten G.C. (1993). Land Resource Economics and Sustainable Development. UBC Press, Vancouver.

Verburg P.H. (2006). Simulating feedbacks in land use and land cover change models. *Landscape Ecology*, 21: 1171–1183.

Verburg P.H. and Overmars K.P. (2009). Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landscape Ecology,* 24: 1167–1181.

Verburg P.H., van Berkel D.B., van Doorn A.M., van Eupen M. and van den Heiligenberg H.A.R.M. (2010). Trajectories of land use change in Europe: a model-based exploration of rural futures. *Landscape Ecology*, 25: 217–232.

Waldhardt R., Bach M. and Borresch R. (2010): Evaluating Today's Landscape Multifunctionality and Providing an Alternative Future: A Normative Scenario Approach. *Ecology and Society*, 15: Art 30.

Walz A., Lardelli C., Behrendt H., Grêt-Regamey A., Lundstrom C., Kytzia S. and Bebi P. (2007). Participatory scenario analysis for integrated regional modelling. *Landscape and Urban Planning*, 81: 114–131.

Walz, A., Brand F., Braendle J., Briner S., Elkin C., Hirschi C., Lischke H., Schmatz D.and Lang D. (2010). Do all mountain regions react to the same drivers of change? How to customise IPCC scenarios to regional analysis? *Global Change and the World´s Mountains Conference, 26-30 Sept 2010, Perth, Scotland.*

Wiborg, T., McCarl, B. A., Rasmussen, S. and Schneider, U. A. (2005): Aggregation and Calibration of Agricultural Sector Models Through Crop Mix Restrictions and Marginal Profit Adjustments. *Paper presented at the XIth EAAE Congress, Copenhagen.*

Wissen U., Schroth O., Lange E. and Schmid W.A. (2007). Approaches to integrating indicators into 3D landscape visualizations and their benefits for participative planning situations. *Journal of Environmental Management*, 89: 184–196.

Wu J. (2006). Landscape ecology, cross-disciplinarity, and sustainability science. *Landscape Ecology,* 21: 1–4.

Zander P., Groot J.C.J., Josien E., Karpinski I., Knierim A., Meyer B.C., Madureira L., Rambonilaza M. and Rossing W. (2008). Farm models and economic valuation in the context of multifunctionality: a review of approaches from France, Germany, The Netherlands and Portugal. *International Journal of Agricultural Resources, Governance and Ecology*, 7: 339–360.