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# Assessing the impacts of economic and climate changes on land-use in mountain regions: A spatial dynamic modeling approach

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ABSTRACT

Future land-use changes are predicted to be influenced by both climate-driven environmental changes and concomitant changes in local economic conditions. Assessing the impact of climate change on ecosystems, and the goods and services that they provide, therefore requires an understanding of the dynamic link between land-cover, ecosystem services and economic-driven land-use decisions. The economic land allocation model (ALUAM) simulates the competition between forest and a range of agricultural land-uses to estimate land-use conversions in a spatially explicit manner at high resolution. Using a modular framework, ALUAM was linked with the forest-landscape model LandClim, and a crop yield model, that simulate the response of forests and crops to changes in climate. An iterative data exchange between the models allows a detailed assessment of the dynamic changes in the provision of agricultural and forest based services. We apply our model to the temperature sensitive inner-alpine region of Visp, Switzerland. Our results demonstrate that land-use is influenced directly by environmental shifts and economic decisions, but are also highly dependent on the interactions between these two components. These shifts in land-use will correspondingly affect the provision of ecosystem goods such as food and timber production.



## 1. Introduction

Ecosystems in mountain areas provide a range of important ecosystem goods and services (EGS) such as food and fiber production, habitat diversity and protection services (MEA, 2005; Messerli and Ives, 1997). These services contribute significantly to regional income (Grêt-Regamey and Kytzia, 2007) and without their provision life would hardly be possible in these regions.

Most ecosystems in mountain areas are an amalgamation of natural components and components that have been modified by human activity, such as agriculture and forestry (Körner et al., 2005). Land-use and associated EGS are therefore dependent on natural processes and external environmental drivers (Schröter et al., 2005). These factors, such as climate change, modify the capacity of ecosystems to provide EGS. Concurrently, land managers might modify their land-use investment in specific goods and services depending on economic conditions such as changes in prices for agricultural products or changes in agricultural policy (Gellrich et al., 2008). Therefore changes in prices for agricultural products, or in agricultural policy, can impact EGS provisioning in a similar extent to climate change. To assess future EGS provisioning, and to evaluate policy measures to mitigate potential future shortages, it is therefore necessary to understand the interplay between climate change, economy and land-use change in the provision of EGS (Euliss et al., 2010).

A challenge that has to be resolved when evaluating and modeling land-use change in mountainous regions is the topographic complexity that defines these regions and has a large impact on land-use decisions (Gellrich et al., 2008). Mountain ecosystems are very sensitive to changes and subtle shifts in the environment can have a large impact on land-use dynamics (Houet et al., 2010). Forest growth – and subsequently the provision of services by forest ecosystems – is dependent on local conditions such as slope and local climate that influence growth and changes in forest composition and biodiversity. Topographic complexity also affects agricultural land-use directly as it has a strong influence on microclimate and soil characteristics. Both are determining factors for potential yield of grassland and crops. In addition, to cultivate steep and varying slopes specialized, and therefore expensive, machinery is needed. Climate change induced shifts in production capacity can lead to important changes in land-use. If production

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potential is affected negatively, land cannot be cultivated in a profitable manner anymore (Gellrich et al., 2007). If maximum yield increases as a result from climate change in certain locations this can also lead to a less intensive land-use, if the additional production capacity cannot be used profitably since there is no demand for it (Henseler et al., 2009). In both cases the parcels with least suitable topography will be abandoned. Additionally changes in land-use are also induced by shifts in the economic environment. To assess changes in the provision of EGS it is therefore necessary to incorporate the topographic complexity into the modeling framework.

When evaluating potential land-use changes, differences in the time frame in which different EGS are produced and managed must also be considered. The length of production cycles is different between agriculture and forestry. Accordingly the frequency of decision making and the time needed for adaptation to changes in the environment are different. In agricultural production, cycles are short with decisions made on a yearly base. These short cycles provide the advantage that adaptation measures can be implemented rapidly by changing the management. In forest dominated ecosystems production cycles are rather long, demanding a more enduring management to ensure future provision of EGS. These differences in the frequency of decision-making have to be considered when simulation interactions between different EGS types. There exists a variety of modeling studies which deal with how changes in climate, policy and markets will impact land-use (reviews in, e.g. Agarwal et al., 2002; Aspinall and Hill, 2008; Irwin and Geoghegan, 2001; Koomen et al., 2007; Lambin and Geist, 2006; Schaldach and Priess, 2008). Furthermore, there is an increasing body of the literature focusing on ecological and economic interactions in agricultural and forest areas at different scales. Verburg and Overmars (2009) present a model at the European level which explicitly takes into account national policy and market changes on a national (or even international) level. Holman et al. (2005) present *RegIS* a modeling approach to assess impact of climate and socio-economic scenarios on EGS provision at a local and regional scale. *RegIS* however does not consider competition between agricultural and forest land-use. In contrast, the *InVest* modeling framework presented by Nelson et al. (2009) is an approach for assessing the impact of different land-use change scenarios on EGS provision. These models provide important knowledge about the influence of climate and economy on land-use change and the provision of EGS. Yet, in these studies land-use is not simulated at the scale at which land-use decisions are made in mountainous regions, and/or climate change is not taken into account.

In this contribution we present a model which provides a detailed assessment of shifts in land-use in a mountainous region of Switzerland under the assumptions of two climate and economic scenarios. Our approach incorporates the combined effect of climate and economy changes on different spatial levels – from parcel to region. Because of its modular framework the model could be adapted to other regions and to other climatic and socio-economic scenarios. This allows a spatially explicit quantification of the provision of EGS, both today and in the future. We focus on two EGS, food and timber, since they are affected by both changes in economic environment and changes in climate, and their provision is one of the goals of Swiss agricultural policy (Herzog et al., 2005). In addition, because of interactions between these marketable EGS and other non-marketable EGS (Nelson et al., 2009), our evaluation of food and timber can be used to extrapolate the impact of land-use changes on other ecosystem services.

## 2. Method

The assessment of changes in land-use and EGS is accomplished in three steps (Fig. 1). In step one, in the absence of land-use change, the direct impacts of climate change on forest development and crop yields are calculated for each year between 2010 and 2080. This step involves amalgamating three data sources: (1) Within each simulated parcel (100 m × 100 m) the potential yield of all agricultural and forestry activities (for an overview see Table A.1) is simulated by the forest-simulation model LandClim and the crop yield model. (2) Spatially explicit data are calculated for each parcel. A digital elevation model (Swisstopo, 2005) is used to calculate elevation and slope of each parcel. Swiss Land Cover Statistics (SFSO, 2009) are used to determine which parcels are suitable for cultivation and a soil utility map (FOAG, 2000) is used to rate the different parcels according to their suitability for the land-use activities. Swiss Land Cover Statistics (SFSO, 2009) was used to calculate the distance of all parcels to the next farm. (3) Administrative data, e.g. the production zone the parcel is lying in, are assigned to the parcels.

In step two, these spatially explicit yield estimates are combined with policy and market scenarios in the economic model *Alpine Land Use Allocation Model (ALUAM)*. ALUAM then simulates land-use decisions based on a profit maximizing approach. The

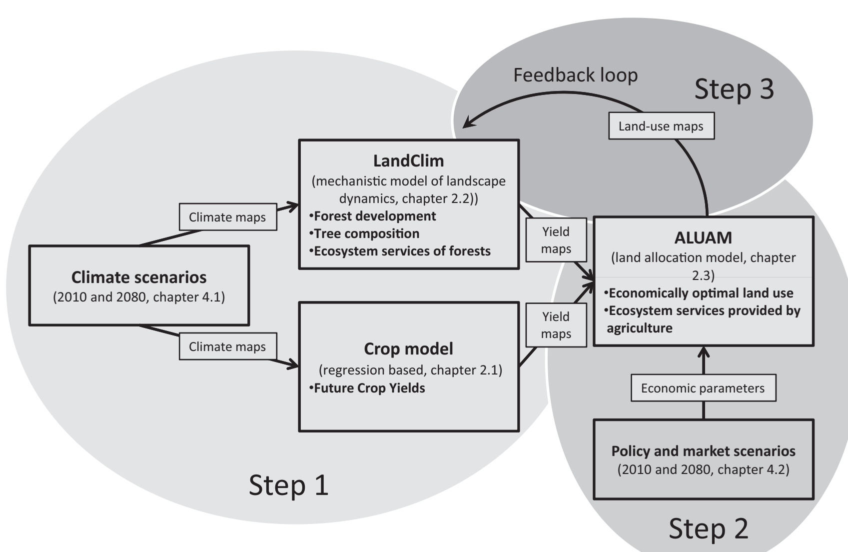


**Fig. 1.** Linkages between the different submodels of the presented framework.