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Influence of land-use dynamics on natural-hazard exposure

Master Thesis

For the fulfilment of the requirements for the Degree of

Master of Science in Mountain Forestry

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Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Vienna, 06/06/2016

Giacomo Piazza

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Last but not least, I would like to express my thankfulness to my girlfriend Natalie, for sharing with me these important years in Vienna.

List of abbreviations

ASCII	American Standard Code for Information Interchange
BMLFUW	Austrian Water Engineering Administration
BUWAL	Swiss Federal Office for Environment, Forest and Landscape
CLUE	Conversion of Land Use and its Effects
CORINE	Coordination of Information on the Environment
DEM	Digital Elevation Model
Dyna-CLUE	Dynamic Conversion of Land Use and its Effects
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
HQ	Flood Discharge
IPCC-SRES	Intergovernmental Panel on Climate Change-Special Report Emissions Scenarios
LOGIT	Logistic Regression
ÖROK	Austrian Conference on Spatial Planning
ROC	Receiver Operating Characteristic
VoGIS	Vorarlberg Geographic Information System
WFD	European Water Framework Directive
WLV	Austrian Torrents and Avalanche Control

Abstract

Increasing surface of settled area and the concentration of highly valuable assets in exposed areas lead to higher probability of losses.

Using the land-use change model Dyna-CLUE 2.0, the dependencies between natural hazard exposure and spatial-planning were tested until 2030. It was selected an area composed by eighteen municipalities in the Ill-Walgau in Vorarlberg (Austria).

Four scenarios were built in order to end up with future landuse maps, which were afterwards combined with actual hazard zoning. Excluding climate change effect, it was observed how the exposure changes with changing landuse.

The modelled output depends very much on the quality of the database. There is a positive contribution due to the introduction of the restrictive policies – 431 ha of “urban” are exposed in the *Overall Growth* scenario with no restrictions, while 409 ha are exposed with the introduction of heavy restrictive policies. But, the stronger the restrictions are the less is their impact on the final outcome. The number and the typology of the driving factors affect heavily the land allocation: the spatial pattern with a reduced number of drivers results less clean – e.g., the “urban” is spread out rather than concentrated in the vicinity of already urbanized areas.

The modeled scenarios are not expected to fully represent the reality, since the incorporation of all the variables brings several uncertainties. However, underlining the presence of these uncertainties, should lead to the development of legally-binding restrictive rules, in order to be able to structure effective landuse management tools and design the proper mitigation measures.

Zusammenfassung

Eine zunehmende Siedlungsfläche in Verbindung mit der Konzentration von Werten in exponierten Lagen führt im Falle von Naturgefahren zu der Möglichkeit höherer Verluste.

In vorliegender Arbeit wurden untersucht, wie sich die Exposition gegenüber alpiner Naturgefahren in Abhängigkeit einer sich ändernden Raumnutzung ändert. Hierzu fand das Landnutzungsmodell Dyna-CLUE 2.0 Anwendung, der Modellierungszeitraum wurde bis zum Jahr 2030 definiert. Als Testgebiet dienten die achtzehn Gemeinden der Region Ill-Walgau in Vorarlberg (Österreich).

Aufbauend auf vier Szenarien wurde eine mögliche zukünftige Landnutzung modelliert, und in Kombination mit einer Verschneidung mit den Gefahrenzonenplänen wurde eine sich ändernde Exposition quantifiziert. Die simulierten Ergebnisse hängen stark von der Qualität der Datengrundlage ab. Die Einführung von planerischen Restriktionen – wie ein Bauverbot in der Roten Gefahrenzone – hat einen positiven Einfluss auf die Fläche und somit Anzahl der exponierten Objekte: die Fläche sinkt dabei von 431 ha in der Kategorie „urbane Entwicklung" auf 409 ha. Es wurde auch beobachtet, dass eine Zunahme von Restriktionen immer geringere Auswirkungen im Sinne einer Verminderung der Exposition von Wertobjekten hat.

Die Anzahl und die Typologie der im Landnutzungsmodell zur Anwendung kommenden „Driving Factors" hat einen starken Einfluss auf die Landallokation: die Raumentwicklung mit einer reduzierten Anzahl dieser Faktoren geschieht räumlich unregelmäßig verteilt, so konzentriert sich beispielsweise der Landnutzungstyp „städtische Entwicklung" nicht unbedingt um bereits existierende Siedlungsflächen.

Als Ergebnis der Arbeit bleibt festzuhalten, dass das Ergebnis der Modellierung nicht zur Gänze die Realität widerspiegelt, da das Zusammenspiel der Variablen eine gewisse Unsicherheit mit sich bringt. Diese Unsicherheit wäre umgekehrt ein Grund, über rechtlich bindende Regelungen zur Restriktion in der Entwicklung bestimmter Landnutzungskategorien nachzudenken, um die Exposition von Wertobjekten gegenüber Naturgefahren zukünftig zu verringern.

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1 Introduction

1.1 Background and problem statement

In the recent past the magnitude and frequency of natural hazard events has increased notably worldwide, along with global GDP (MunichRe 2014). A higher number of elements are exposed to natural events, therefore the risk is higher. Risk is defined as the expected losses (of lives, persons injured, property damaged, and economic activities disrupted) due to particular hazard for a given area and reference period. Based on mathematical calculations risk is the product of hazard, vulnerability and cost of the elements at risk. Therefore the overall economic losses caused by natural hazards have increased as well. The extensive floods occurred in August 2005 in the Alpine area, for instance, caused €2.6 million of monetary losses among Austria, Germany and Switzerland (Munich Re 2007). Both estimated losses and understanding about natural hazards have increased during the past decades (Munich Re 2001), which is contradictory as we may logically think. A more natural hazards-aware society should lead to a decrease in losses. It is not the case, since the physical damage has been increasing in volume in the past decades. Risk is increasing, due to climate change and societal change: more severe hazards are happening due to changing climatic patterns and conditions, while society is concentrating assets and people in punctual places leading to a higher exposure. Increasing surface of settled area and the concentration of highly valuable assets (e.g. technology) in exposed areas (Munich Re, 1999) lead to higher probability of losses. The historical shift from traditional economies, based on cattle husbandry and extensive agriculture, to the industry- service-based society in mountain areas, favored a type of clustering which reflect the low importance and low awareness of the planners towards mountain hazard risk (Fuchs & Keiler 2008; Promper et al. 2014).

Landuse involves arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Di Gregorio 2005). These changes are due to many reasons, or driving factors: socio-economical, environmental, accessibility to land, land-tenure, etc. (Verburg et al. 2004a). The change of those factors may cause many effects and impacts, at various levels and at different time spans. The relation between driving factors and impacts is not straight (Claessens et al. 2009). Natural and socio-economical processes are for a big extent determined by the spatial configuration of landuse, thus a better understanding of the temporal dynamics of the change in configuration is fundamental to assess the impact of future decision-making, in the context of natural hazards management.

Land use refers to the human use the land resources according to the needs and characteristics of the land (Di Gregorio 2005). Land use is thus the product obtained by the human exploitation of the environmental characteristics (Claessens et al. 2009), in order to fulfill many requirements (e.g. food production, housing, recreation, industry, etc.). Being the interface between natural and man-made processes it not free from conflicts. The importance of natural processes and the human action and decision-making are equal in the context of land use change studies (Verburg 2006). Human society and its needs are setting somehow the priorities in the context of spatial planning, to satisfy those needs having a limited resource, space. For example, in a world facing high urbanization rates, the demand for building land is pressing upon the not-built space, thus different policy tools have been developed to try to overcome this issues: transferable development rights, land and property taxation, building bans, etc. (Geoghegan 2002). The multiple goals that land use has to fulfill might generate tensions: intensive farming, natural conservation, housing and productive activities, public needs and transportation networks, have all different requirements and the effect of the human activities and impacts on the land use are still a matter of debate (Fohrer et al. 2005). Very often the total conciliation of all these goals and approaches is impossible and even tougher if we think that the land use is not stable and immutable over time. It is though in constant change at every spatial and temporal scale, thus, in the spatial-planning context, many different demands for such a limited space must be weighed against each other (De Groot 2006).

Spatial-planning is not only acting at a local scale affecting merely the local dynamics. Rather, its sphere of impact might enlarge towards larger scale when we think about integrated flood management (Thaler et al. 2016). Flood policy and risk management plan debates are shifting towards inter-local solution, in a complex relation involving State-to-local top-down dynamics and local-to-local approaches (Thaler et al. 2016). Since water is running from the highest point to the lowest point of a catchment, the decisions and measures implemented in the up-stream communities surely affect the lower stream communities. Therefore, institutional interventions and steering are often required in order to set the right priorities, even though they generate often conflicts (Thaler et al. 2016).

We selected an area composed by eighteen municipalities in the Ill-Walgau in the Austrian federal state of Vorarlberg. The choice is due to the interesting spatial arrangement of the area which alternate a well-developed infrastructure network, a high percentage in forest cover, industrial areas and two relatively big cities, Feldkirch and Bludenz. As we observed, the past two decades did not face substantial landuse changes – in comparison with the decades from the 50's to the 90's – hence we may also expect that the next three decades will follow the same trend of the recent past. Still, the spatial planning is or should be one fundamental pillar of risk management, although is not yet a homogenous and standardized element in risk management in Austria (Holub & Fuchs 2009).

1.2 Research objectives

The aim of the study is to test the possibilities and limitations of the land use change model Dyna-CLUE in the Alpine region, simulating the future landuse dynamics until 2030. The model was developed to simulate landuse change based on empirically quantified interaction between landuse and its driving factors (Verburg et al., 2002). The model is composed by two distinct modules: non-spatial demand module, which calculates the area change of class at each year, and spatially explicit allocation procedure, which is based on a combination of spatial analysis, empirical decisions and data and dynamic modeling. Moreover, there is a set of decisions based by the user opinion (e.g. restricted area) which regulates the land allocation.

Four scenarios were built based on several sources (e.g. ÖROK) in order to end up with four future landuse maps. We cross-checked these maps with natural hazard zoning by the WLV (Austrian Torrent and Avalanche control) and the zonation by the BMLFUW (Austrian Engineering Administration). Excluding a significant change in the next 30 years in the hazard propagation (intensity, frequency, etc.) – hence excluding climate change effects – we observed how the risk changes with changing landuse patterns throughout the years. In their study de Moel & Aerts (2011) underline how the urban landuse classes have specifically a high contribution to the total flood damage in the Netherlands – in particular the residential category shows the highest contribution to the total flood damages – due to the urban development and "invasion" of the flood plains, which reduce the riparian zones, channelize the rivers and allocate the land to agriculture and/or infrastructures and buildings.

The study wants to stress the importance of spatial planning and restriction policies in mitigation of natural hazards. Exclude, or underestimate the importance of the spatial planning leads and will lead to a dangerous partial interpretation of the reality. It has been already observed the change in natural hazards management from structural, security-based policy towards an integrated, risk-based approach (Fuchs & Thaler 2013), although in many instances was not enough and stronger political rules and restriction are needed. Mitigation of natural hazards should always start from the compilation of hazard maps and risk maps in order to gain important elements to proceed with a sustainable and holistic landuse planning. On a local scale, especially in the alpine valleys, the awareness of public administrations is of crucial importance at the planning table. One good example of coping strategy and dynamic reassessment of the spatial planning took place in the village of Cortaccia (Italy) the debris flow occurred during the thunderstorm of June 2001 led the local administration to review the land allocation, excluding the deposition zone from the already-in-project enlargement of the residential area which was no longer suitable to feed the future housing-needs of the village (Willerich et al. 2008).

1.2.1 Research aims and questions

Starting from the stated above situation, the objectives of the research would like to address the interface between natural hazards and land use changes through the simulation of future land use change scenarios until 2030. The overall aim of the thesis is to examine how the land use change dynamics affect the exposure to natural hazard in the European Alps. The underlining of the complexities and uncertainties laying at the base of the exposure dynamics could be taken as hint for the planners and decision-makers to adapt and implement ad-hoc policy interventions at a local level. Using the land use change model Dyna-CLUE, the thesis will address the potential and limitation of the model while analysing the effects that different restrictive policies have on the land use development and dynamics until 2030.

The following issues will be addressed in the context of this study:

(1) *Test the potential and limitation of the Dyna-CLUE in an alpine environment.*

Despite the model has been tested several times in several contexts around the world, in the alpine context the extreme variability from one valley to another requires ad-hoc approaches tailored to the local conditions. Moreover, being the CLUE a general land use change framework that could be easily adapted to diverse situation for different goals, the design and construction of the modelling files are strictly related with the aim of the research. Thus, the construction of the model and its behaviour in such analyses was tested.

(2) *Gain an idea of the potential exposure when no restrictions are implemented.*

How would the exposure to natural hazards change when no restrictive policies are implemented? Namely, which are the outcomes if the actual building-bans and the present laws would be removed or changed? This goal aims at exploring the exposure dynamics without any restrictions until 2030 across the four scenarios.

(3) *Analyse future spatio-temporal dynamics of exposure to natural hazards until 2030, while testing the model responses to different land use restriction policies.*

How do different restriction configurations impact on the future exposure to natural hazards? The test aims at setting up three restriction configurations – light, medium and heavy restrictions – with increasing areas. Each scenario has then to be simulated testing each of the configurations and the resulting exposure to natural hazards analysed.

(4) Test the sensitivity of the Dyna-CLUE to the number and to the quality of the driving factors.

How the set of drivers influence the simulated results? Since these variables are the main drivers of land use change, the goal is here to assess how the CLUE is affected by the range of these factors, quantitatively and qualitatively. The procedure is to reduce the total number of the driving factors, paying also attention on the typology of the removed drivers. The quantity but also the quality of the variables are fundamental in determining the land use changes, according to the literature. Since the set of drivers covers a broad range of characteristics – social, economic, environmental – the aim is to assess the dynamics involved.

1.3 Structure oft he thesis

In the following lines the content and arrangement of the thesis will be addressed. The Chapter 2 provides a critical reflection of the existing literature and the actual praxis in the contexts of spatial planning and natural hazards management. In the Chapter 3 the localization of the study area and useful social and environmental elements of the Ill-Walgau will be provided. The Chapter 4 will address the methodology that was followed in the research as well as the data collection and management. The results and discussion of the simulations are in the Chapter 5. Here are presented the outcomes from the model construction to the simulated land use maps, with their implications in the context of land use change and natural hazards management. The Chapter 6 displays the conclusions of the thesis and the research possible outlook. Then follow the Appendixes, where some further details on the data sources and model input files are given.

2 Theoretical background

Mountain hazards are defined by Kienholz et al. (2004) as *"potentially damaging processes resulting from the movement of water, snow, ice, debris and rocks on the surface of the earth"*. Losses caused by mountain hazards are the results of the interaction between the physical environment and the human stakes (i.e. activities, buildings, assets, etc.) (Wisner et al. 1994). Natural hazard risk is the function of the event (i.e. mass movement, flood) and the number of people and/or objects which are exposed to that hazardous event, which determines the extent of damage (e.g. Fuchs et al. 2004). Objects and people have different degrees of vulnerability to one specific hazard (Wisner et al. 1994). Vulnerability to natural hazard is, according to the definition given by Wisner et al. (1994), *"the characteristic of a person or group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard"*. Vulnerability thus is independent from the chance of occurrence of an adverse event, while it is indeed dependent from the inherent characteristics of the system (Sarewitz et al. 2003). Therefore, risk is the combination of vulnerability and hazard (Wisner et al. 1994), while vulnerability is the susceptibility to damage, which merely exists by itself (Alexander 1997). Dealing with natural risk under a holistic point view means considering social, economic and ecological aspects through the principle of sustainability (Kienholz et al. 2004). The concept of risk proposed by BUWAL (1999) and followed by the insurance praxis, is based on a systematic model structured in three elements. (1) Risk analysis (what could happen), deals with a scientific characterization of the system involved; (2) risk assessment (what is it allowed to happen): the society fixes the threshold values of acceptance of loss; (3) risk management and actions to be undertaken in order to mitigate the risk (i.e. monitoring, structural measures, communication, pre-alarm, etc.).

2.1 Concept of risk

Dealing with risk, means to take into account the entireness of the system considering social, economic and ecological elements (Kienholz et al. 2004). This comprehensive approach was introduced at the end of the 1980s after a series of adverse event across Europe that triggered the development of the "concept of risk". This concept was developed in the context of natural hazard management in order to quantify the degree of the hazard (Bründl et al. 2009). "What to protect and at which cost?" and "what are the residual risks?" (Kienholz et al. 2004). These are the questions from which the discussion started to turn when the concept of risk was developed, being the concept of risk more and more a key topic among the scientific and professional communities (Fuchs et al. 2013). This tool provides a universally applicable framework that has to be adapted at each single situation. The cycle consists in three phases, as already mentioned above: (1) Risk analysis (2) risk assessment, (3) risk management and actions to be undertaken in order to mitigate the risk. (1) The first elements to be identified are the typology of the hazardous processes involved – intensity, frequency, possible impacts on objects – the elements that are threatened by the hazard – assets, human lives, and infrastructures with their economic values. From the result of this phase the combination of the above players gives the probable consequences of any adverse event (Kienholz et al. 2004). One important outcome is the identification of risk zones, through proper risk maps (Holub & Fuchs 2009). (2) What loss is acceptable ant what is allowed to happen? In this phase the risk is characterized in order to plan and coordinate the following decisions; the result of the risk assessment is the definition in the context of the society of what is acceptable risk and what non acceptable risk (Kienholz et al. 2004), being also the basis for the planning of the prevention and mitigation measures. (3) What has to be done, which measures have to be implemented in order to prevent or mitigate any adverse outcomes. The variety of the measures that can be implemented is huge: technical measures to stop deflect the hazard propagation (e.g. Fuchs & McAlpin 2005; Oberndorfer et al. 2007), biological measures such as protection forests (e.g. Dorren et al. 2004; Dorren et al. 2007; Brang et al. 2008), a combination of the two, and spatial planning that allows avoiding the presence of assets on the hazard track (e.g. Mazzorana & Fuchs 2010; Mazzorana et al. 2012).

2.2 Vulnerability

Vulnerability is strictly linked to natural hazards and it might be expressed under various perspectives: social scientists and engineers and natural scientists tend to observe this concept in different ways (Fuchs 2009). The definition proposed by natural scientists characterizes vulnerability as the expected degree of loss resulting from the impact on exposed elements of an adverse event, with a certain magnitude and frequency (Fuchs et al. 2012). Being vulnerable means to be prone to damages of any nature (Kienholz et al. 2004). The first and more ancient way to reduce vulnerability is to direct activities in areas not exposed to mountain natural hazards (Fuchs 2009). Spatial planning is and it has always been the key feature for risk management. The European Alps is one of the most densely populated areas in the European Union. In fact only the 15-20 % of the whole Alpine Convention territory is actually suitable for permanent settlement (Tappeiner et al. 2008). The communities through centuries of maturated experience have developed according to risk-aware criteria. After the economic boom of the post-war period, though, it seems that other types of interests started to prevail and emerge in the society. Nowadays, mountain agriculture abandonment generates uncontrolled territories within the alpine space. The farmers, throughout the centuries, have shaped the steep slopes in order to make them suitable for their subsistence and as safe as possible for their livelihoods; these slopes, once abandoned tend to return to a natural state, which of course may not meet our criteria of safety and stability. On the other hand, the development of cities with tourism and industry led to the accumulation of assets and activities in the more comfortable valley bottoms, throughout the Alps (e.g. Fuchs et al. 2004; Fuchs et al. 2005). In several instances it is still discernible the old risk-aware spatial cluster of buildings from the new. The shift from traditional economies, based on cattle husbandry and extensive agriculture, to the industry- service-based society in mountain areas, favored a type of clustering which reflect the low importance and low awareness of the planners towards mountain hazard risk (Fuchs & Keiler 2008; Promper et al. 2014).

2.3 Exposure

Exposure is defined by the IPCC SRES (2012), as the presence of people, livelihoods, environmental services and resources, infrastructures and assets in places that could be adversely affected by natural hazards. To be able of interpreting the trends and dynamics in the elements at risk, in order to achieve an effective natural hazard risk management, the availability of data of the elements at risk becomes fundamental (Jongman et al. 2014). Thanks to the improved calculation power and remote sensing technologies, the accuracy about the hazard information rose significantly in the last years. The role of the impact of the exposure is however still underestimated, but in some cases the assumption that the event intensity is proportional to the damages has been rejected; in fact, the land use pattern dynamics, thus the exposed elements, play a major role (e.g. Fuchs, et al. 2012b). historical trends in the exposure to natural hazards are of primary importance to anticipate future scenarios (Jongman et al. 2014), and in the context of integral risk management, decreasing or limiting the number of element at risk is one of the key actions to be undertaken (e.g. IPCC 2012). Unfortunately, in many cases all around the world, the heritage of the old planning decisions continues to influence the present land use planning (e.g. Glavovic et al. 2010), leading to a heavy increase in the exposed building in the last decades (Fuchs et al. 2015).

In the recent past the magnitude and frequency of natural hazard events increased notably worldwide, along with global GDP. However, in the most developed countries, and among them Europe, the number of fatalities caused by natural hazards is decreasing since the beginning of the 20th century (MunichRe 2014). In fact, since the 50s strong efforts were invested in the erection of technical mitigation measures aiming at decreasing the negative effects of the natural hazards propagation (Holub & Fuchs 2009). However, the overall picture is not clear, and a global standardized assessment method is still missing (Fuchs 2008; Fuchs & Keiler 2008). To provide an example, in the Autonomous Province of Bolzano (IT), since the 1900 a n umber of about 30 000 check-dams and consolidation structures have been erected, 16 % of which do not fulfil the technical requirements (Mazzorana 2008). Therefore, through the actual approach in many cases protective goals are not met, due to the big socio-economic – and climatic - transformations which happened in the alpine area in the last fifty years. Very often, the associated underlying residual risk is not completely assessed (Mazzorana & Fuchs 2010).

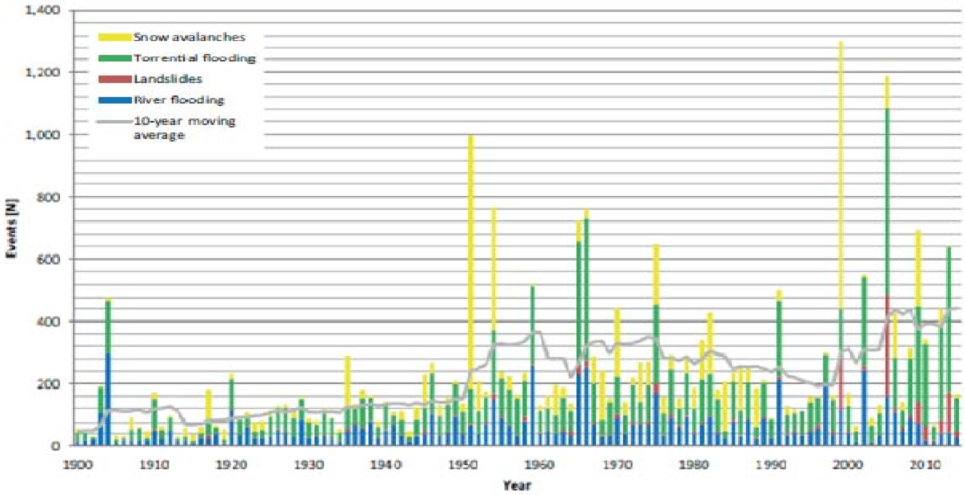

Figure 1. Annual number of documented natural hazards causing losses in Austria. Data source: Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, 12/2014.

Especially when we deal with mountain regions like the Alps, the situation becomes more complex. The space constraints given by the morphology of the valleys, led in the past years to the development of the few suitable areas. The result is a concentration of elements in potentially prone-to-natural hazards areas, which lead to a higher pressure on the land use in comparison with a flat area (Mazzorana et al. 2009). The space limitations, the morphologic and social characteristics of the alpine area are peculiar elements which very often offer to the decision-makers extreme challenges, in order to guarantee and maintain dynamic economies (Mazzorana et al. 2009). Hence, in spite of considerable efforts to protect the endangered areas the amount of losses as a result of torrential processes for example has been considerably rising as stated by many authors (Fuchs & McAlpin 2005; Oberndorfer et al. 2007; Balbi et al. 2015).

A higher number of elements are exposed to natural events, therefore the risk is higher. Consequently the overall economic losses due to natural hazards increased as well. The extensive floods occurred in August 2005 in the Alpine area, for instance, caused €2.6 million of monetary losses among Austria, Germany and

Switzerland (Munich Re 2007). Papathoma-Köhle et al. (2015) estimated the losses occurred as a consequence of repeated debris flow events in the summer 2012, in the municipality of Vipiteno/Sterzing, South Tyrol (Italy). The estimation calculated through a damage assessment tool, sums to €1.3 million of monetary losses due to these events in one single location. Not only monetary are the losses. In Switzerland, according to Hilker et al. (2009), the total financial damage caused by floods, debris flows, landslides and rock-falls amounts to €8 000 million, within the period 1972-2007. In the period 1945-1990 Guzzetti (2000) reported almost 10 000 fatalities due to landslides and debris flows in Italy. The Fig. 2 shows the increasing trend of overall losses caused by natural hazards world-wide. In Austria, the 13,3 % (319 026 buildings ca.) of the total buildings are exposed to natural hazards; among them the 93,5 % are exposed to one hazard type, while 6,5 % are exposed to more than one natural hazard type (Cammerer et al. 2013; Fuchs et al. 2015).

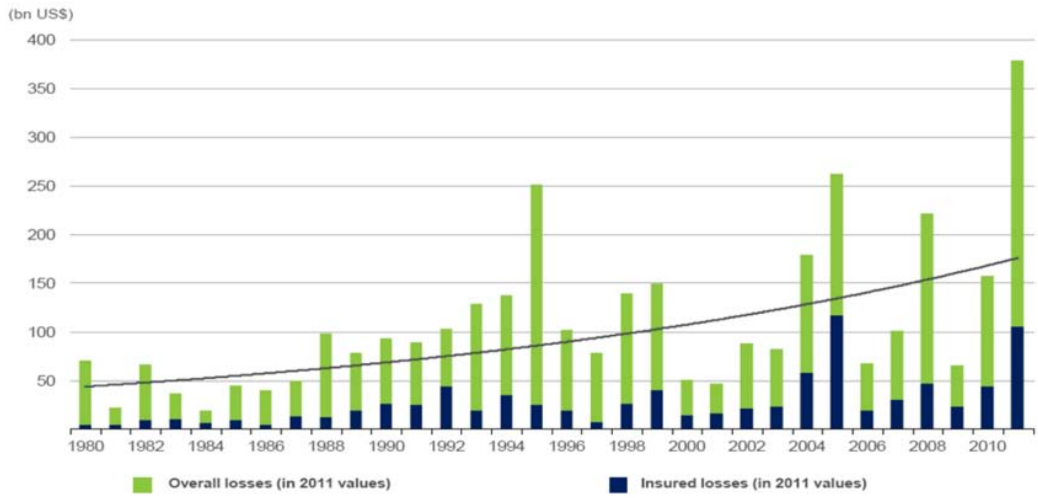

Figure 2. World-wide overall (green) and insured (blue) losses from 1980 to 2011, in billion US$ (Munich Re 2012).

Barredo (2009) proposed a slightly different approach to look at the picture. He considered the major floods occurred in thirty-one European countries between 1970 and 2006 – major floods are considered the event with losses larger than 1000 million in 2006 US$. The total amount of losses in these period in normalized US$ was 140 billion. The Fig. 3 shows actually no clear trend of increasing losses due to flood events, it shows rather a fluctuation with peaks and a 5-years average of annual flood losses of 4000 US$. Barredo attributes the differences to natural variability in the events, rather to a defined climatic shift, or climate change, like other authors claim (i.e. Allamano et al. 2009; Bouwer et al. 2010; Mazzorana et al. 2012; Staffler et al. 2008). The Fig. 2, as Barredo claims, has to be taken with caution. The series in fact contains all the effect of the societal changes occurred over time. These many factors, like inflation, changes in population and exposure, per capita real wealth, etc. contributed to the falsifying picture. Another aspect that surely would mitigate the general picture is to consider in the proper way the positive mitigation contribution to flood frequency given by the implementation of protective measures (Barredo 2009). This last statement is yet not completely supported by Jongman et al. (2015). The authors, although they recognise the economic growth as the main driver of increasing losses, stated that if the climate change leads to increasing frequency and magnitude, and the pre-capita wealth continues, economically losses from flood will increase despite the actual adaptation measures. In their study Jongman et al. (2015) saw a human society at the global level, able to reduce successfully the vulnerability to floods thorugh adaptation and mitigation measures. Yet to cope with more numerous and intense events, the actual strategies might not be enough, being further measures certainly needed (Jongman et al. 2015). In other words, despite the differences in the data display of the literature, also excluding climate change as a variable, the exposure dynamics play a crucial role that has to be acknowledged and assessed case by case.

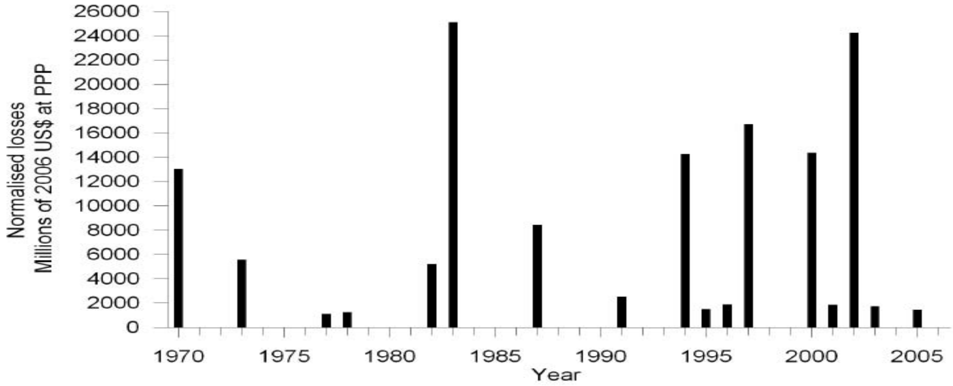

Figure 3. Annual flood losses from major flood disasters (>1000 million in 2006 US$) occurred in Europe between 1970 and 2006 (source: Barredo 2009). The picture shows no increasing trend.

In Austria, in the period between 1972 were reported 4894 damaging torrent events; within this database the events were subdivided between typologies using an ex-post classification (Oberndorfer et al. 2007). They identified 0,3 % of floods, 21,8 % of floods with bedload transport, 49,2 % of hyper-concentrated flows and 28,7 % of debris flows – the average direct loss per event amounted circa to €175 000 (Fuchs et al. 2013). Dealing with mountain hazards, the snow avalanches play also a big role. Since the 50s more than 1600 persons have been killed by avalanches only in Austria, which means circa 30 fatalities and € 25 million losses on a yearly basis (Höller 2007). Of course, when talking about avalanches fatalities we should mention that the majority of the victims caused by the snow are ski-mountaineers, with the exception of the winters 1950/52, 1953/54, 1964/65 and 1998/98 (Galtür). In these years catastrophic avalanches affected directly the villages causing high losses and a high number of victims (Land Tirol 2000). Thus clearly, the behavior of the exposure to mountain hazards is dynamic rather than static. The assessment of these dynamics and their nature should be an essential component within the integrated hazard risk management (Aubrecht et al. 2013), although very often these complexities are neglected or underestimated (Cammerer et al. 2013).

Natural and artificial elements (Fig. 4) are essentially related one to the other, being the artificially-built features embedded in natural features (Liu et al. 2007). Hence, nature affects strongly the man-made dimension and vice-versa. Human activities on the other hand are composed by fluxes of goods and people, assets with their values and functions according to our society, recreational activities, etc., which run/take place according to the environment (Liu et al. 2007). To make an example we may borrow the terminology from the computer world and call the environment hardware and the activities software. How does the software react when some modifications of the hardware happens? Namely, how the human activities are affected when the structures and network they rely on have been severely damaged or changed (e.g. Tacnet et al. 2013)? How should we structure our activities in order to be less vulnerable and more resilient to changes (e.g. Fuchs 2009)? And on the other hand, how should we structure the environment we live in (natural + artificial = hardware) in order to prevent and/or mitigate adverse and uncontrolled modifications or damages (e.g. Van Beek & Van Asch 2004)?

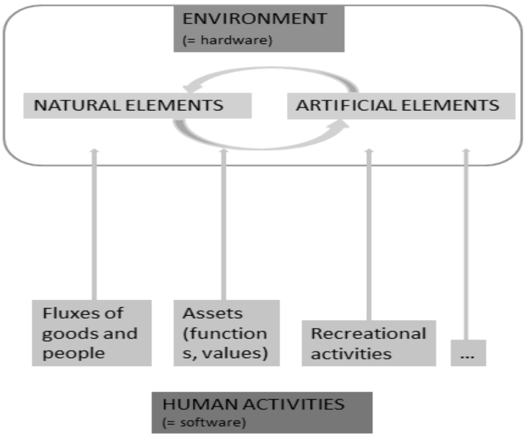

Figure 4. Interactions between the Environment (hardware) and the Human activities (software).

The physical environment (natural as well as artificial) where we live and where our activities take place has its own functionality determined by its architecture. Human beings make use of this functionality in order to best displace their activities, which are directly supported by the architecture of the physical environment (i.e. waterways, roads and railways) (e.g. Liu et al. 2007; Mazzorana & Fuchs 2010). Such activities, represented mainly by fluxes and values, have specific requirements and they are design and tested to meet and fit the physical environment. However, what is still not clear are the mechanisms of feedback existing between the natural elements and artificial ones (Liu et al. 2007). The latter in fact push continuously towards the rationalization of natural elements (Mazzorana & Fuchs 2010): several past experiences and tragedies testify that mankind is not yet fully aware of the consequences of certain decisions (i.e. Vajont, 1963 (IT); Galtür, 1999 (AUT)). What we should achieve is the capability to predict the effects that multiple changes in the physical environment creates on the physical environment itself and on human activities, possibly before changes occur/are made (Bohner & Arnold 1996). Experts and planners must understand which are the cause-effect relations within the multiple elements, in order to effectively predict the impact of those changes (e.g. Kok et al. 2007; Claessens et al. 2009; Cammerer & Thieken 2013). The natural elements constituting the physical environment: climate, orography, geology, vegetation, geomorphology, etc., while the artificial elements are: landuse, roads, railroads, houses and buildings, industrial plants, etc. As I already mentioned, these features are not static, actually they are dynamic and in a continuous state of transformation (Liu et al. 2007). The sketch below (Fig. 5) provides the practical examples on what it will be considered in the context of this study, while showing the details of the features involved and their relationships in the system.

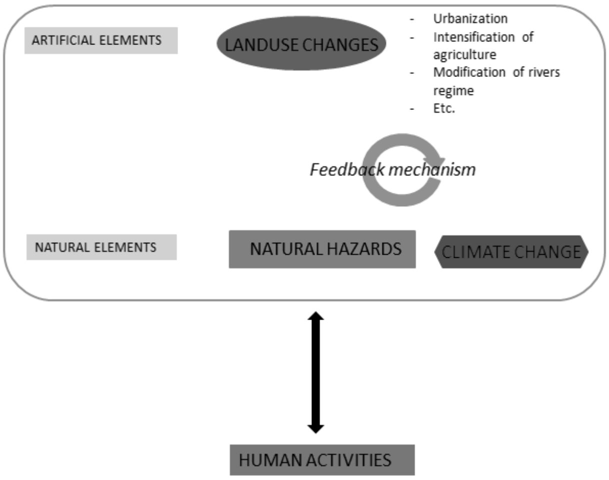

Figure 5. Interactions between the Environment (hardware) and the Human activities (software), with the features considered in this study.

Focusing on the components which constitute risk, we may identify a physical component and a temporal dimension (Aubrecht et al. 2013). The physical part is composed by the geographic limits of the hazardous process, including the spatial pattern taken by the observed mass movement throughout the landscape, the velocity, the density, the impact forces, etc. On the other hand, risk changes over time for several reasons (Aubrecht et al. 2013): for examples, due to climatic changes which affect the physical characteristics of the process we may see the risk increasing (e.g. Staffler et al. 2008). Moreover, risk is increasing independently from the mere natural and physical elements of the hazard itself, but also it increases due to man-made modifications of the environment which is under the threat of that given hazard (e.g. Fuchs et al. 2013). Risk is no absolute part of the mountain hazards themselves; it is rather, as already mentioned, the quantification of the hazard. Thus, since risk is calculated as the losses that are caused by the process, the interactions hazard-societal structures become the crucial concept from where to start the integrated disaster risk management (Aubrecht et al. 2013). The dynamics of the exposure to mountain hazards is heterogeneous and complex, involving small-scale patterns which are proved to be hard to identify, analyze and model, since its temporal variability, the local topography and the built environment are finely interacting between each other (e.g. Mazzorana et al. 2009).

2.4 Dynamics of risk

Static approaches towards risk brought in the past management praxis to have significant gaps leading often to erroneous adaptation and mitigation measures (Fuchs et al. 2013). The spatial and temporal variation of risk It has been often neglected in the literature and in the praxis (Fuchs et al. 2012). Risk to natural hazards varies strongly over time and space (Fuchs et al. 2013) being landscape processes and societal structures which determine the risk itself continuously changing (Cutter & Finch 2008). The driving forces of risk are highly affected by spatiotemporal variability and in order to implement effective strategies of mitigation, preparedness, response, etc. a flexible approach sensible to local variability and characteristics is needed (Cutter & Finch 2008). The consideration of the interactions between the natural and social components and their dynamics is fundamental for the developing of comprehensive management strategies (Aubrecht et al. 2013). Thus, a better understanding of short- and long-term variability as well as spatial variability is needed (Fuchs et al. 2013). Exposure and vulnerability are dynamic, they vary in fact over time and space, and are strongly dependent to environmental, geographical, economic, social, etc. factors (IPCC 2012). The IPCC identifies in the demographical changes in the context of climatic variability, as main drivers of increased exposure and risk to natural hazards globally.

2.4.1 Temporal dynamics

Risk changes over time, due to many factors and at different scales. Time influences the dynamics of the elements at risk on the long-term and on the short term. Furthermore, time affects both sides: it changes the hazardous processes from one hand, and it has impacts on the elements exposed on the other (Fuchs et al. 2013; Fuchs & Keiler 2008).

Long-term temporal dynamics: exposure and hazards

Even without taking into account climate change effects (Mitchell 2003) - considering the mountain hazards unchanged in their characteristics (magnitude, intensity, propagation, etc.) during the last century, the dynamics of the impact of the hazardous events has strongly shifted towards higher values, since the development of the mountain areas undertaken in the last fifty years (Mazzorana & Fuchs 2010). The damage potential resulted from the massive societal changes from the traditional rural society to the industry- tourism- or leisure- oriented society increased abruptly in this period (Fuchs & Keiler 2008). Due to this socio-economic changes which led to the concentration of the human-made environment – with assets, goods and lives – in along the more suitable valley bottoms. Therefore, within the risk management process, the temporal variability of the damage potential has to be taken into account (Fuchs & Keiler 2008). The Fig. 6 (Fuchs et al. 2005) takes as examples two mountain villages, Davos in Switzerland and Galtür in Austria; these two small settlements were involved in the touristic boom that took place in the 50s, which means that a lot of houses and hotel were built in the past fifty years to host the wave of seasonal visitors willing to enjoy the mountains. The two mountain resorts had parallel but slightly different development histories. From the 1950 to the 2000, the total number of buildings in Davos has almost tripled and their total value increased by a factor of four. In Galtür, the total number of buildings inside avalanche-prone areas rose by a factor of 2,5, while their value jumped up with a factor of almost six (Fuchs & Keiler 2008). Thus, on the long-term it has been observed an increase in the number and values of the elements at risk, or threatened by one or more hazards.

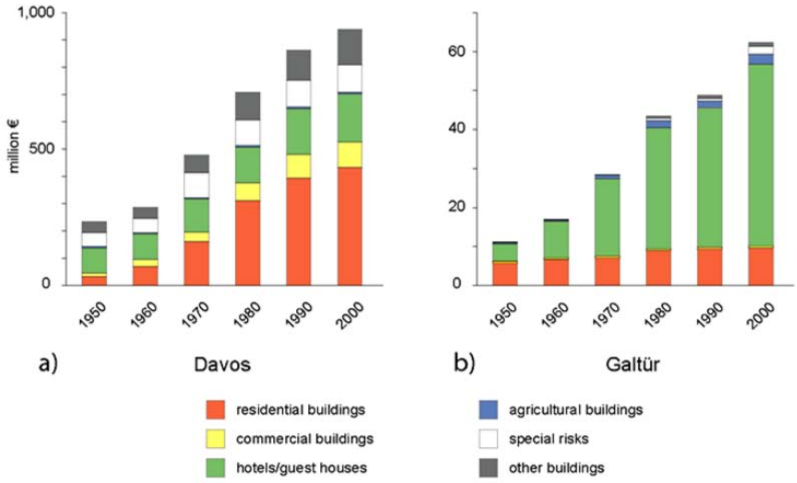

Figure 6. Elements at risk: increase in the long term of the values of the buildings threatened by natural hazards over time. The locations are very big winter resort a) in Switzerland, b) in Austria. The diverse typology of buildings displayed in the figure is showing the temporal dynamics of the elements exposed to natural hazards. (from Fuchs et al. 2005)

Many evidences of the changing environmental and climatic patterns have been given in the last years by many authors, belonging to different disciplines (Easterling 2000; Rupp et al. 2012). The climatic fluctuations are directly responsible for the alterations in the hazard activity (Fuchs et al. 2013). The European Alps show a temperature increase of twice as much as the global average since the late 19th century (Auer et al. 2007). Beniston (2012) claims that the temperature in the Swiss Alps has been raising since the 1900 three times more than the global average; regional models suggest that by 2100 the winter temperatures will raise by 3 – 5 °C and the summer values by 6 – 7 °C, in this part of the Alps. The alterations in the temperature patterns throughout the year have major impacts on the rock/slope stability for example; permafrost, which is present abundantly at high elevation in the Alps, is degrading due to warm temperatures. This new phenomena is considered to be one major driver of increasing slope instability, which is causing unexpected toppings or failures in unprecedented locations (Gruber & Haeberli 2007). Big and small failures are happening quite commonly in the Alps in the last decades, due to high summer temperature (Beniston 2012). Another long-term driver for changing exposure is precipitation. The alterations in the precipitation distribution, quantity and intensity are of fundamental importance in the context not only of natural hazards, but also regarding economy – water is used for agriculture, power, snow making, etc. In the Alps, as in the other mountain regions in the world, precipitation under the form of snow are regulating run-off phenomena, water storage; any changes in the amount of snow, its yearly cover duration and timing of the snow-melt have long-lasting environmental and economic impacts (Beniston 2012). While these phenomenon and their direct effect on the system hydro-climatic alterations have been well documented, it is still less known what are the effects of these changes on the geomorphological processes and on the sedimentation-erosion regimes in the mountain catchments (Fuchs et al. 2013). Due to the increasing human influence on the natural systems (e.g. water retention, dams, streamlining of the watercourses, etc.) and human presence in hazard-prone areas, an increased in the likelihood and adverse impacts of natural events is expected (Mazzorana & Fuchs 2010). These consistent temporal dynamics affect strongly the hazard behavior and the hazard exposure on a single catchment and on the alpine region as a whole, having big impacts on the single valley, but also on the foreland regions, which receive the water coming from the upper part of the catchments (Fuchs et al. 2013).

Short-term temporal dynamics: exposure and hazards

Short-term risk fluctuations supplement the basic long-term trend, especially when we deal with fluxes of people and goods which move through the networks (railroads, roads, waterways) (Zischg, et al. 2005b). Since risk is the combination of hazard, vulnerability and reachability, which correspond to exposure and presence (Tacnet et al. 2013). Thus, in a context where the elements at risk are moving, the concept of timing and therefore presence are of primary importance. However, the temporal variability of damage potential on transportation networks has been so far not deeply investigated (Zischg et al. 2005a). The daily/seasonal fluctuations of traffic in regions affected by tourism are significantly high (Zischg et al. 2005b). In fact, As defined by Wilhelm (1997), the damage potential of road networks is calculated as a derivate of the number of persons potentially endangered, which is an expression of the traffic density. The Fig. 7, taken from Zischg et al. (2005a) shows the temporal variability of the relations between the avalanche hazard level, based on the usual scale from 1 to 4, and the traffic density; the death risk is computed taking into account the choice to drive on the summer (no protection measures are provided) or the winter road (running in the gallery).

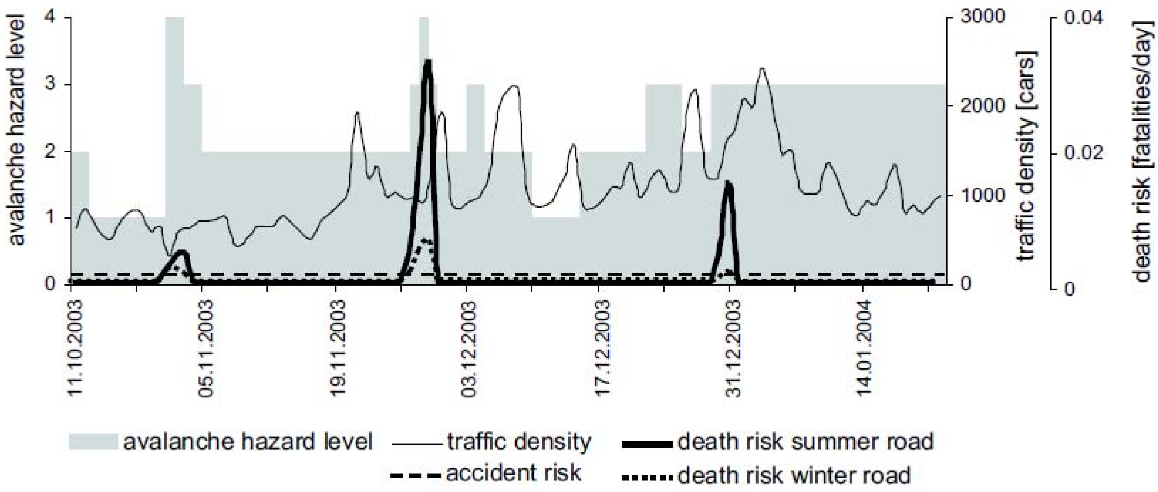

Figure 7. Collective fatalitiy risk along the Sulden road from Prad to Sulden via "summer road" and via "winter road" – example for the situation between 1 November 2003 and 23 January 2004 (from Zischg et al. 2005a).

From the hazard perspective, the short-term variability shows a high influence on the overall risk. Mountain meteorological conditions and development are often unpredictable. The intensity of the events is not always correctly assessed on a fine topographic scale by the meteorological models: strong summer thunderstorm may lead to localized extremely high amount of rain in a very short time, or winter *stau* conditions and continental streams may lead to considerable amount of snowfall (Höller 2007). The Fig. 8 shows the seasonal variability due to tourism but also the diurnal variability due to tourism and local people activities of the avalanche exposure in Galtür.

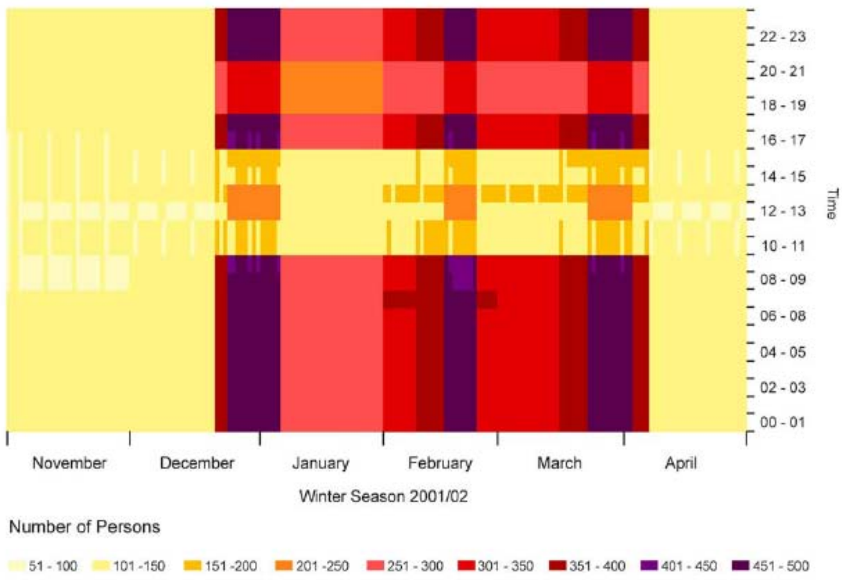

Figure 8. Variation in the number of people exposed to avalanche during the winter season in Galtür. The seasonal and the diurnal fluctuations are well displayed. (from Keiler et al. 2005)

As the Fig. 9 shows, the long-term basic disposition is formed by the immobile values like buildings or any other structure; to be summed on this basic long-term trend there is the highly-variable short-term disposition of mobile values like persons (Fuchs et al. 2013). These mobile values form a special part of the damage potential due to their high variability – which is often correlated to high predictive uncertainties – and because they can be removed from the endangered area; thus, in order to structure an efficient warning system and evacuation plans, the pattern of the short-term variability have to be taken into account and correctly assessed (Keiler et al. 2005).

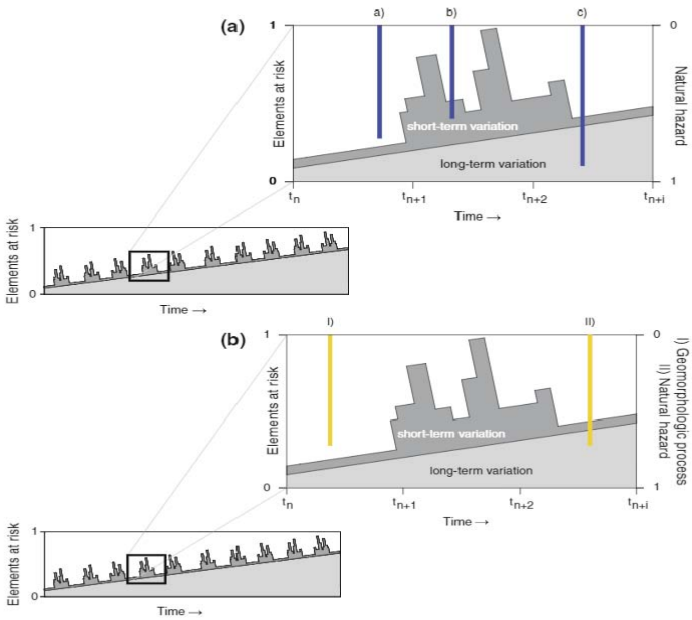

Figure 9. The concept of short- and long-term risk variation given a dynamic process disposal (higher magnitude, different outreach) (a); the same concept shown with a steady process disposal (b) (from Fuchs et al. 2013).

2.4.2 Spatial dynamics

During centuries, human being have been shaping the Earth surface according to their needs; the trajectory of these alterations are not uniform throughout the world, it rather alternates periods with rapid increase in the scale and rate of change, normally in determined regions. The most recent of these change outbreaks, took place in the last 50 years, and it is different for its magnitude, pace and kind (Turner II et al. 1990). Spatial variability, is not only concerning the nature of the change itself in different locations; it is also underline how the friction at the interface human activities/nature is going be more critical, with different magnitudes according to the varying spatial scales (Turner II et al. 1990). Therefore, the spatial aspect must be addressed in the context of sustainable development in mountain regions, with special concern on the assessment and management of hazard risk (Fuchs et al. 2013). Moreover, this friction is going to be even stronger in the alpine area, due to the significant spatial limitations caused by the geo-morphology and climate of the region, which represent a constraint to the human development (e.g. Satistik Austria 2008; Mazzorana et al. 2009). In Austria, only the 38,7 % of the territory is suitable for permanent settlements, commercial activities or agriculture (Statistik Austria 2008), while in the area considered in this study it is only the 27,43 %. Since the big percentage in high alpine areas, the concept of land suitability, or net-settable land, plays in Austria an important role. In fact, big surfaces are either rocky bare land, steep slopes or surface permanently covered by ice or permafrost. Moreover, the forested land and water bodies have also to be subtracted from the final result. Thus, for this space are competing agriculture, settlements and infrastructures.

Table 1. The eighteen municipalities of the study area, with their total surface and the percentage of land suitable for settlements (modified from Statistik Austria 2008).

Municipality	Area in km²	Suitable land in km²	Suitable land in %
Bludenz	29,94	10,31	34,44
Bludesch	7,59	4,01	52,83
Bürs	24,61	3,35	13,61
Bürserberg	13,73	2,94	21,41
Lorüns	8,35	0,88	10,54
Ludesch	11,26	4,73	42,01
Nenzing	110,09	10,18	9,25
Nüziders	22,07	5,92	26,82
Stallehr	1,64	0,59	35,98
Thüringen	5,67	3,57	62,96
Düns	3,45	1,18	34,20
Feldkirch	34,33	21,2	61,75
Frastanz	32,26	7,67	23,78
Göfis	9,05	4,77	52,71
Röns	1,45	0,73	50,34
Satteins	12,69	5,03	39,64
Schlins	6,03	4,07	67,50
Schnifis	4,87	2,24	46,00
Total	**339**	**93**	**27,43**

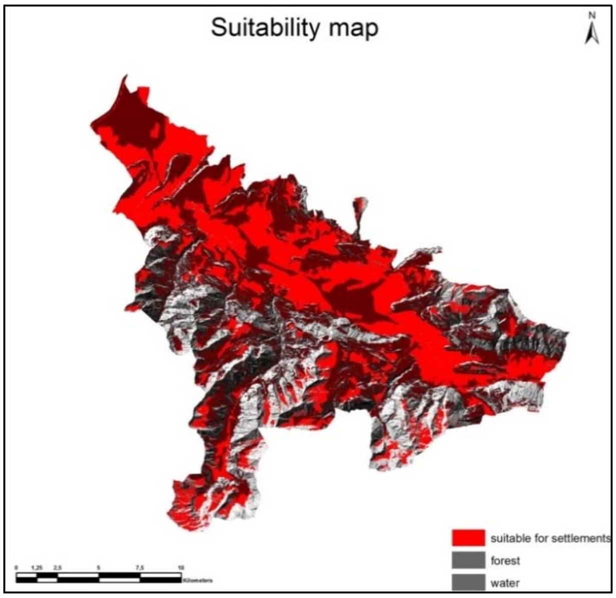

Figure 10. Map showing the land suitable for permanent settlements (in red). Once we identified the suitable land – the criteria of the identification according to Statistik Austria (2008) are slope less than 30 degrees and altitude less than 1600 m; then we subtracted the portion of land which belongs to forest and water bodies.

In the portion of suitable land (Tab. 1, Fig. 10), the spatial distribution and the local patterns of the mountain hazards has to be taken into account (Fuchs et al. 2013). Thus, it is clear that there is a conflict between the growing human needs, which led to an increasing usage of the available area for settlement purposes, and the natural elements and conditions; this is particularly noticeable along the main Alpine valleys and in the foreland regions. In the municipality of Davos in Switzerland, for example, the value of the building increases towards the valley bottom (Fuchs & Bründl 2005). At a catchment level, the magnitude of the influence of the channel dynamics during the event is of major importance since it turned out to be a major source of uncertainties. In fact, through the simulation models the flow properties and the depositional behavior are assessed, however the effects of changing in the channel morphology and associated transportation of anomalous debris (e.g. woody debris), were found to cause a non-linear amplification of the negative outcome of the processes, especially referring to the intensity (Mazzorana et al. 2009). Due to the human encroachment in the valley bottoms and the reduction of the natural water retention caused by intensification of agriculture and land usage for housing, and with the consequent streamlining of the watercourses, an increase in the likelihood and adverse impacts of flood event is expected (Mazzorana & Fuchs 2010). Furthermore, the complexity of the morphology in mountainous areas, which causes a high unpredictability of the spatial dynamics, is thought to be a major source of uncertainties during the modelling phase, leading to the need of refine and re-calibrate the actual measures and strategies (Mazzorana et al. 2009). The small scales patterns of topography, soil and rainfall have a big influence on the run-off production (Wood et al. 1988). However, it is also known how as the spatial scale of the catchment increases, the catchment tends to smooth the complexities given by the micro-topography and therefore, the differences in the water run-off generation (Wood et al. 1988).

This conflict has been challenging the national and local administrations in the Republic of Austria, but of course also in the other Alpine states, and strategies to prevent and/or mitigate the negative outcomes might be traced back to the Middle Ages (Fuchs et al. 2013). The first legal regulations in Austria were implemented by the Austrian-Hungarian Monarchy at the end of the 19ht century. These strategies have been changing throughout the years and according to the specific needs and sensibility of the society at a given time: form the permanent concrete technical measures, to the afforestation efforts and from the temporary bio-engineering measures to the passive mitigation, or hazards zoning, introduced in the 1970s (Fuchs et al. 2013). The aim of these different typologies is to deflect or block the process, decreasing the reach-distances, the magnitude and the frequency; while regarding the passive prevention, the aim is to reduce losses without directly influencing the process, but moving away the values at risk (Fuchs et al. 2013).

2.4.3 Scenarios and uncertainties

The possibility to better cope with this high variability and fluctuating dynamics are the scenarios. The purpose of the scenarios is to focus the attention on cause-effect dynamics and to identify the decisive points of intervention (Mazzorana et al. 2009). A scenario is thus a possible picture of the future state of the system; possible hence underlying uncertainties. The classification of scenarios proposed by Ducot & G.J. (1980) is structured through three different axes. The vertical axis, express the cause-effect relation between, for instance, the triggering processes and their outcomes in terms of torrential events. On one pole exploratory scenarios are situated, being the outcomes of a given set of causes; on the opposite pole there are the anticipatory scenarios, which identify the possible causes given a set of effects (Mazzorana et al. 2009). On the two opposite poles of the horizontal axis are present the descriptive and the normative scenarios, also called human-choice axis. The normative scenarios incorporate political and planning decisions, while descriptive scenarios show the set of possible occurrences from a certain situation (Mazzorana et al. 2009). On the diagonal axis, namely time axis, on the opposite poles there are the trend scenarios, showing the possible evolution of a certain variable within a time span, and the cross-sectional scenarios which provide the description of the system at a given point in future time (Mazzorana et al. 2009).

In the risk management context, the processes involved act on multiple scales: three dimensional spatial scale and temporal scale. The concept of return interval (e.g. hazard zonation), for example, which actual strategy relies on for mitigation measures, relates the outcome intensity (e.g. inundation depth) with certain trigger events (e.g. rainfall). These concept does not allow to address uncertainties due to sudden morphological changes in the channel, or the effect of the presence of woody debris in the bed; these two examples may cause the failure of the mitigation measures system that was based on the return interval concept (Mazzorana et al. 2009). In the context of planning management and land use pressure, the driving forces leading the scenarios are based on certain parameters such as institutional change, population dynamics, society/consumption habits, economy, energy (fossil, renewable), transport mobility, agriculture and forestry, tourism and environment (IPCC 2012). The participatory analysis of these European-wide and global-wide themes/factors within the different stakeholders, allowed generating the four scenarios adapted to the Austrian context (ÖROK 2008). For example, if in the next 20 years the population increases by a certain percentage, the land use pressure might be higher in the peri-urban areas. Also in this case, the uncertainties are present and might make the basic assumptions fall: the crisis of the refugees (e.g.) caused by far away wars is for sure an element introducing variability in the system and that was not expected. The problems to deal with are composed by multiple facets, in other words they are essentially structured by a long chain of sub-problems. We may not always be acquainted with the hierarchy of this chain, and what we set as a primary problem might be a secondary problem (Mazzorana et al. 2009).

Temporal and spatial variations in the process behavior represent a big limitation in the modeling science (Mazzorana et al. 2009). In order to a have the most realistic and detailed picture a cross-sectoral approach (Mazzorana et al. 2009) should be followed, incorporating several aspects and issues which are apparently not directly linked with natural-hazard domain: political decisions (e.g. migrations, economic changes, demographic development, structure of the society, etc.). Thus, the efforts should go to the direction of the dissection of the initial problem re-definition (critical system analysis) in order to find the plausible future developments and design the proper feasible pathways and achieve the optimal protection level against natural hazards (Mazzorana & Fuchs 2010).

2.5 Land use change: feedbacks and processes

Human use of land resources, namely landuse, is the product of human needs and biophysical characteristics of the land. Land use involves "the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (Di Gregorio 2005). Land use is affected by a large series of interacting processes which involve the bio-physical environment and the human socio-economic sphere (Claessens et al. 2009). The importance of natural processes and the human action and decision-making are equal in the context of land use change studies (Verburg, 2006). The relation between these feedbacks and their outcome, namely the land use change, is not linear at all; it is though a dynamic system, where the effect of one process may amplify or hinder the outcomes (Claessens et al. 2009). Furthermore, the temporal and spatial scales on which the processes act are different, showing often threshold effects (Veldkamp et al. 2001). In other words, small changes in apparently much localized processes may lead to big destabilization of the system, which might be also delayed in time. On the other hand, the cumulative effect of many small scale land use have a global impact on climate conditions due to different patterns in carbon emissions and land surface characteristics (Claessens et al. 2009).

Land use is not stable and immutable over time. It is though in constant change at every spatial and temporal scale. These changes are due to many reasons, which will be referred as driving factors: socio-economical, environmental, accessibility to land, land-tenure, etc. The change of those factors may cause many effects and impacts, at various levels and at different time spans. The relation between driving factors and impacts is not so straight. It is though a complex interrelation turning around two central questions: (1) *what drives landuse changes and why* and (2) *what are the impacts on the environment and on the human society of these changes*.

Between landuse and natural hazards are present bilateral relations which are still not completely and fully addressed, despite the increased awareness of the threats involved (Thaler 2014). Most of the studies on flood risk, for instance, are focused on hydrological changes due to temperature increase (Allamano et *al.*, 2009), or global change impact on floods and droughts (Lehner et *al.*, 2006). The paper by Lehner at al. (2006) takes into account not only climate change, but also current and future water use. Mostly, these studies (partially) neglect to address the impact that landuse changes have on flood propagation and flood exposure. It was observed in fact, that human encroachment increases flood exposure in the urban areas (de Moel & J. C J H Aerts 2011), and landuse changes affect directly hydrological processes and flood propagation: agriculture changes the infiltration patterns and built environment leads to increased runoff (Ferreira et *al.*, 2009; O'Connell et *al.*, 2007; Chiari et *al.*, 2010) hydrological processes causing a different flood behavior on the other hand. Other studies that have been carried out in the European Alps, are focused on the effects on ecosystem functionality on a regional scale after the changes in the landuse occurred in the past decades (i.e. Kulakowski et *al.*, 2011). Besides the ecological impacts, it was observed that landuse changes, especially agriculture abandonment in the alpine valleys, may increase in the short term the potential risk of natural hazard by increasing the probability of avalanche formation and soil erosion and by decreasing the soil infiltration capacity (Cernusca et al. 1996). Recent studies from the Netherlands provide a more comprehensive spatio-temporal analysis of flood risk addressing climate change, landuse change, socio-economic projections, taking into account a full set of inundation scenarios. The aim of the study conducted by Bouwer et *al.* (2010) is to "identify the main factors that affect potential river flood risks in the future, combining the assessment of the losses resulting from a large set of inundation scenarios". This approach allows a more detailed and complete assessment of changes in future flood risk than previously possible. Since the impact of landuse change and increasing exposure affect future flood risk at least as much as climate change, risk reduction measure and a correct spatial planning will be of primary importance in risk mitigation (Fig. 11) (Bouwer et al., 2010). Similar studies have conducted also an Alpine valley in Tyrol (Austria), with the aim of investigating the possible shift in flood exposure due to landuse changes (Cammerer et al., 2013) and observing the historical changes and future projection of flood damage potential on residential areas (Cammerer & Thieken 2013).

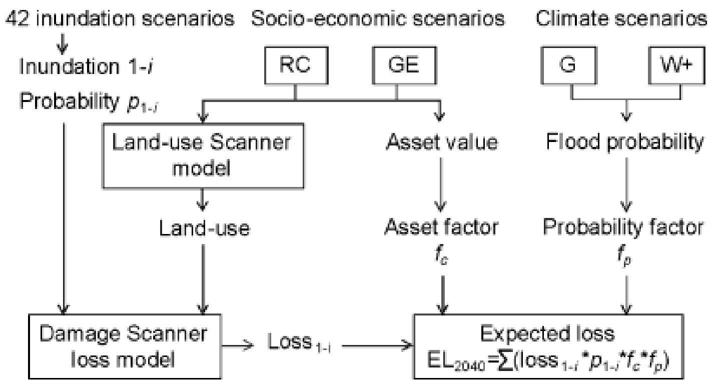

Figure 11. Framework of the approach proposed by Bouwer at al. (2010).

As the Figure 12 shows, the interaction and feedbacks between land use change and natural hazards are multiple and multi directional. The following lines are a summary of the existing literature regarding these relationships.

(1) *Land use change affects the exposure on natural hazards*. In their study de Moel et al. (2011) underline how the urban landuse classes have specifically a high contribution to the total flood damage in the Netherlands – in particular the residential category shows the highest contribution to the total flood damages – due to the urban development and "invasion" of the flood plains, which reduce the riparian zones, channelize the rivers and allocate the land to agriculture and/or infrastructures and buildings. This displacement of assets on a place which is "naturally designed" to store and release flood water (Wheater & Evans 2009) has the consequence of increasing the vulnerability to flood.

(2) *Land use change affects the propagation of natural hazards*. Landuse changes have big effects on hazards propagation, influencing hydrological processes. Deforestation for instance decrease the evapotranspiration and water interception by the leaves (Ferreira et al. 2009; Wheater & Evans 2009), contributing to smoother runoff peaks discharges. The highest runoff volumes are found in constructed areas (Ferreira et al. 2009). Another highly discussed example affecting infiltration patterns is agricultural intensification, which is reported by many authors (i.e. O'Connell et al., 2007; Wheater & Evans, 2009), as loss of hedgerows, increase in field size, installation of drainage systems, soil compaction, etc. Hence, for management purposes the study of the sensitivity of streamflow (i.e.) to landuse change is of primary importance on a local scale, since the effects might be significant (Hurkmans et al. 2009). There are many studies that address the role of the vegetation as a powerful mitigation tool of the natural hazard management (e.g. Dorren et al. 2004; Dorren et al. 2007; Schwarz et al. 2010; Papathoma-Köhle & Glade 2013; Chirico et al. 2013). In fact, forests have either negative effects on the stability in the source zone of a rock fall for instance, but positive effects in the transit and deposition zones (Dorren et al. 2007). Furthermore, we it has also to be considered that a scale effect is present (Wood et al. 1988), thus also the influence of the land use and land use changes on the hazard behavior might decrease with increasing spatial scale.

(3)

(4) *Propagation of the hazards represents often a driver that causes a change in the land use*. On the other hand, when the natural hazard has been acknowledged, the planners might consider undertaking a certain intervention on local landuse in order to protect whatever it is threatened by the aforementioned natural hazard. Mitigation measures such as afforestation (protection forests) and/or technical measures have the objective to prevent and/or protect from natural hazards – i.e. blue reservation areas in the Austrian hazard zoning (Republik Österreich 1975) must be kept free for further technical or biological control measures. In the Alps for example, protection forests located upslope in the subalpine/alpine regions might prevent the release of avalanches, decrease the runoff, etc. (Berger & Rey 2004). Hence in this case the presence of the hazard has led humans to change the local landuse in order to try to avoid/mitigate the occurring of a certain adversity. Moreover erosion and sedimentation processes change the soil depth affecting the suitability of a certain parcel of land for agriculture (Verburg, 2006).

(5) *Climate change has impacts on both, natural hazards and land use*. Vulnerability to natural hazards of residential zones leads to the compilation of hazard maps and risk maps, which then should identify the zonation in order to proceed with a sustainable and holistic landuse planning (Kunz & Hurni 2008). On a local scale, especially in the alpine valleys, the awareness of public administrations is of crucial importance at the planning table. In the case of the village of Cortaccia (Italy) the debris flow occurred during the thunderstorm of June 2001 led the local administration to review the land allocation, excluding the deposition zone from the already-in-project enlargement of the residential area which was no longer suitable to feed the future housing-needs of the village (Willerich et al. 2008).

Furthermore climate change introduces in the system more uncertainties, acting on both features. It has been proved in fact by many studies due to climate change the natural hazards are increasing in their frequency and magnitude (i.e. Allamano et al. 2009; Bouwer et al. 2010; Mazzorana et al. 2012; Staffler et al. 2008).

Climate change affects landuse and landuse changes through agriculture management worldwide (e.g. agriculture intensification) (i.e. Olesen & Bindi 2002; Smit & Cai 1996). Specifically, increased greenhouse gas emissions will be followed by an increasing in cereal productivity in north-western Europe and reduced productivity in Mediterranean region (Olesen & Bindi 2002), where a parcel of land that was suitable for growing a certain kind of crop twenty years ago, might not be suitable any more due to droughts. It is also true the contrary process, namely landuse change might generate a variation in the global and local climate through the modification of the albedo, the atmospheric concentration of carbon dioxide and methane and the surface fluxes of heat and water vapor – thus it change the spatial and temporal patterns of thunderstorms (Pielke 2005).

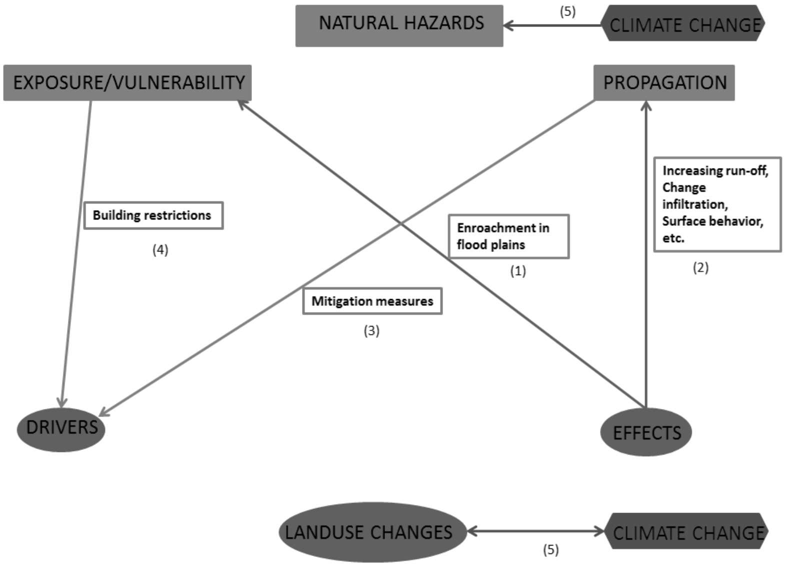

Figure 12. Interactions and feedback mechanism between landuse change, natural hazards and climate change.

Studying the spatial and temporal dynamics of the exposure to natural hazards using a landuse change model and hazard scenarios should therefore take into account the feedbacks between the driving factors and the effects of landuse change (Verburg, 2006). The example taken from Verburg (2006) aims at illustrate the impacts on a landscape level of the feedbacks between different processes in Southern Spain: erosion and sedimentation shallow the soil which becomes unsuitable for agriculture, leading to land abandonment (Fig. 13).

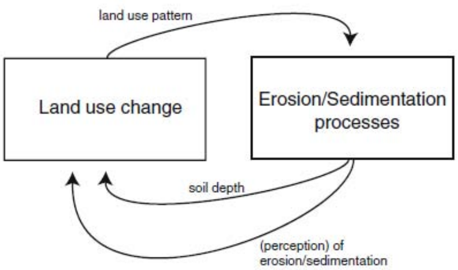

Figure 13 Feedbacks between soil erosion/sedimentation and landuse change implemented for Southern Spain (Verburg, 2006).

Besides the effects feedbacks on the erosion/sedimentation regime, land use has a strong impact on the water regime of the rivers; even without accounting for the climate change effects, the extreme floods and low flows are strongly interrelated to changes in the land use, which in some instances showed strong local influence on the water regime (Hurkmans et al. 2009). According to Hurkmans et al. (2009), a land use change in the upper stream or in the tributary catchments, affect heavily the downstream river flow – an example is afforestation/deforestation in the tributary catchments. However, an effective combination in the land use changes (e.g. deforestation/urbanization) in different part of the basin, might be able to significantly affect the floods/low flows regime (Hurkmans et al. 2009). Therefore, again the comprehension of the spatial and temporal scales is fundamental to be able to interpret the outcomes of the feedbacks involved in the complex relation between changes in the land use and natural hazards. To stick on the over cited example, deforestation acts on a very short temporal scale, and its effects are also rapidly observable; urbanization might take longer time to be implemented, while afforestation take longer time, either to be implemented and to be effective under an hydrologic point of view (Hurkmans et al. 2009).

3 Study area

It has been selected an area composed by eighteen municipalities in the Ill-Walgau catchment in the Austrian federal state of Vorarlberg. The choice is due to the interesting spatial arrangement of the area which alternate a well-developed infrastructure network, a high percentage in forest cover, industrial areas and two relatively big cities, Feldkirch and Bludenz. The municipalities are the following: Bludenz, Bludesch, Bürs, Bürsenberg, Lorüns, Ludesch, Nenzing, Nüziders, Stallehr, Thüringen, Düns, Frastanz, Göfis, Röns, Satteins, Schlins, Schnifis, plus Feldkirch – which does not belong to the hydrographic district of the Ill-Walgau, though we included it for the importance that the city has for the socio-economics of the valley (Fig. 14/15).

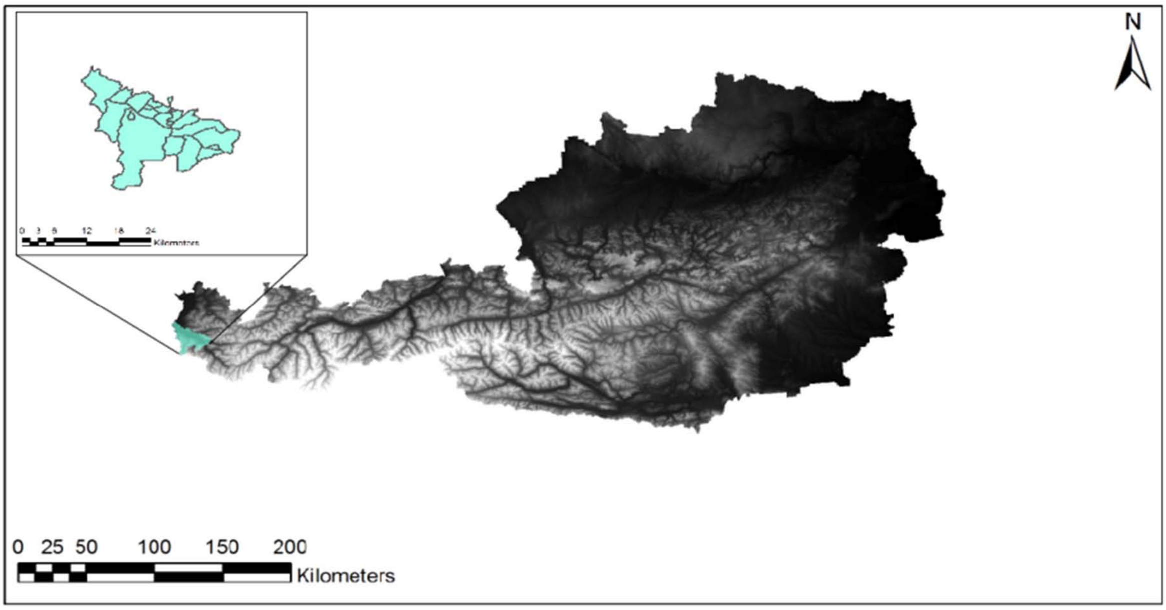

Figure 14. Geographical location of the study area. The catchment is in the westernmost part of the Sate of Vorarlberg in Austria, bordering with Switzerland.

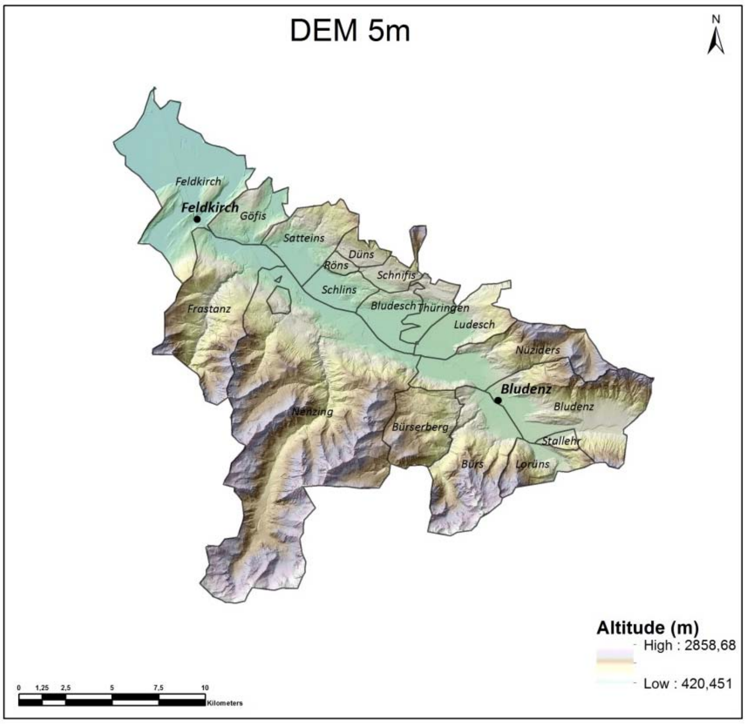

Figure 15. Digital elevation model of the Ill-Walgau. The eighteen municipalities with the two main cities, Feldkirch and Bludenz.

The Walgau is a 20 km long alpine valley, drained by the river Ill, right tributary of the Rhine. The study area covers a surface of about 33 951 ha, with an altitudinal range from 420 to 2858 m a.s.l. The catchment shows a long tradition in the regulation of the waters. Since the 1820s the municipalities along the river changed the flow for agricultural and industrial purposes. This river is regulated by several dams which provide hydroelectric power and in the last 20 years the Austrian Hydraulic Engineering Administration (BMLFUW) cooperated with the local authorities in order to start the implementation of several flood protection structures. Since the 1990s the Ministry for Agriculture, Forestry, Environment and Water Management set new river development schemes in order to enhance the cooperation between upstream and downstream communities. On top of that, we observed a change in the water management policy and as a consequence, in the flood management strategies, especially after the flood event in 2005. In the 2000s the European Water Framework Directive (WFD) and the EU Floods Directive led to the implementation in the Austrian Federal legislation of several measures turned to a more holistic view of the water network, taking into account ecological principles and natural hazards not only under a technical perspective but also under a socio-economical point of view. These measures are implemented through several steps: increase river continuity, increase the biodiversity, implement flood storage structures in the catchment, etc.

After the massive flood event in 2005, the measured flow values used for the determination of the 100 years events (value defining the peak discharge that statistically happens one time in 100 years), has to be reassessed due to change in precipitation pattern and intensity (Fig. 16). Hence, while in inner part of the Federal State territory the peak values do not show significant increase, the north-exposed valleys like the Walgau catchment were highly affected by the event. This leads to the consideration that, in a spatial planning context, the risk perception should reassessed since the average values that defined the hazard zonation have also shifted to higher levels.

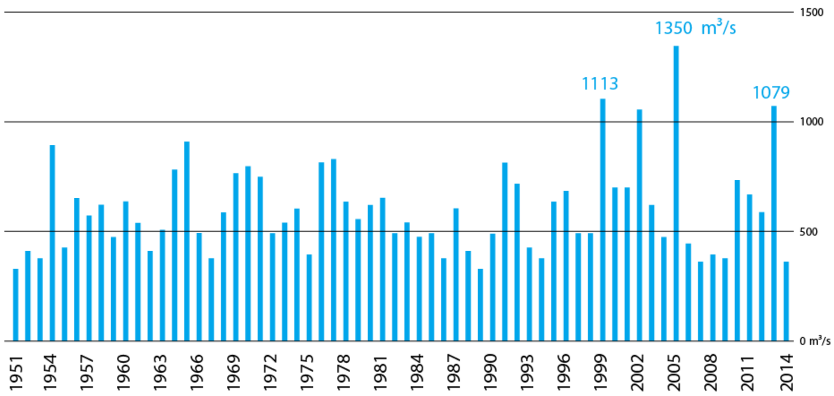

Figure 16. Year rows of the most intense flooding events measured in the Bregenzerach in Kennelbach, from 1951 to 2014 (source: Land Vorarlberg Report 2015).

The diagram displays the comparison between the stronger flood events from 1951 to 2014, pointing out that from the 50s to the year 1999 no big flood event took place in the State territory; from the year 1999 though, four significant events have been recorded. As a consequence of these extreme discharges (Tab. 2), the values for planning and designing the flood protection measures have to be re-evaluated, defining as a base for the HQ100 zonation the new measurements.

Table 2. Capacity of the main rivers of the State. In bold the Ill (source: Land Vorarlberg report 2015).

Water body	Measured Old value	Peak Flow in 2005 *m3/sec*	Measured New value	Losses *Mi€*
Bregenzerach, Mellau	290	450	480	4,2
Bregenzerach, Kennelbach	1200	1350	1450	
Ill	**650**	**689**	**820**	**6,6**
Dornbirnerach	300	236	325	0,5
Litz, Schruns	80	94	105	

The losses after the 2005 flood event, amount at 180 million Euros circa. These losses were subdivided as follows: households, industry and municipalities were affected up to 100 million Euros, while the infrastructure network and the mitigation measures up to 80 million Euros. These losses, as already mentioned above, were concentrated mainly in the valley bottoms.

3.1 Population and socio-economic structure

The Walgau is a dynamic region and productive region. Due to the strategic central position the region is an important communication node linking the Eastern Alps with the Western and Southern and Northern Europe. The main arterial road is the S16 which is the direct western prolongation of the highway A12 of the Inn valley. The S16 then becomes A14 before Feldkirch and then continues its way towards the German State of Baden-Würtenberg. The same layout is followed by the railway. The total population of the area amounts at 82 937 inhabitants and an overall population density of ca. 244 inhabitants/km^2, against the population density of the State of Vorarlberg being 144 inhabitants/km^2. The main centers are Feldkirch in the Northern part and Bludenz in the South, counting respectively 30 943 and 13 701 inhabitants. Together with the lower Rhine valley the Ill-Walgau is an important industrial and productive district of Vorarlberg and Austria overall. With a GDP of €14,1 billion in 2011, the State of Vorarlberg accounts for 4,4 % of the Austrian GDP (European Commission 2016). The State was one of the earliest regions to be industrialized in Austria, and in the recent decades it went through a deep restructuring and modernization of the industrial sector (European Commission 2016). The activity rate of the Ill-Walgau is always above 50 % except for two municipalities – Lorüns (49,6 %) and Düns (48,6 %). Furthermore, in the area more than 5 470 enterprises are present: 4 405 in the tertiary sector, 691 in the secondary and 361 in the primary. The main economic drivers of the region are the electrical, metal, computers, machine building and textile industries. In the latest decades tourism has been gaining more and more importance in the economy. Paper and wood processing, plastic and food industries are also increasing their shares in the recent years (European Commission 2016). Deeply linked with tourism there is the agriculture, spacing from wine-making to alpine cheese production. Table 3 and Table 4 provide a glance of the social and economic structure of the area.

Table 3. Descriptive table concerning the demographic and socio-economical characteristics of the eighteen municipalities, referred to each single municipality. The data have been taken from Statistik Austria and self-elaborated. From left to right: population and population density (yr. 2011; from Bevölkerungsentwicklung 1869 – 2015); private households (from 2012; from Abgestimmte Erwerbsstatistik 2012 - Haushalte und Familien); activity rate (sum of employed and non-employed in 2012; from Abgestimmte Erwerbsstatistik 2012 - Bevölkerung nach Erwerbsstatus); labor force and unemployment (employed and non-employed in 2012; from Abgestimmte Erwerbsstatistik 2012 - Bevölkerung nach Erwerbsstatus); labor structure in the three work-sectors (employees and enterprises count in 2011; from Registerzählung vom 31.10.2011 Arbeitsstätten und Beschäftigte); commuters count (yr. 2012; form Abgestimmte Erwerbsstatistik 2012 - Erwerbspendler nach Pendelziel).

	Population	Private household		Activity rate		Labor force		Unemployment		Labor in I sector		Labor in II sector		Labor in III sector		Commuters
	n (n/km^2)	n	% tot	n	%	n	%	n	%	empl.	enterp.	empl.	ent.	empl.	ent.	n
Bludenz	13.701(457)	6148	2,2	6952	50,6	6471	47,1	481	3,5	159	44	2098	97	4899	822	3760
Bludesch	2.225(293)	891	2,49	1234	55,7	1153	52,1	81	3,7	87	9	193	26	649	83	948
Bürs	3.096(126)	1312	2,34	1662	53,8	1576	51	86	2,8	45	15	583	15	1629	219	1157
Bürserberg	533(39)	193	2,68	280	53,2	265	50,4	15	2,9	12	7	12	6	79	39	197
Lorüns	274(33)	110	2,55	139	49,6	132	47,1	7	2,5	4	2	7	4	36	9	111
Ludesch	3.377(300)	1289	2,57	1796	53,6	1703	50,8	93	2,8	52	26	377	42	525	117	1372
Nenzing	5.986(54)	2378	2,51	3153	52,6	3022	50,4	131	2,2	81	46	2764	56	1720	290	2081
Nüziders	4.870(220)	2049	2,37	2452	50,5	2377	48,9	75	1,5	48	15	877	44	964	239	1829
Stallehr	278(172)	108	2,63	148	52,1	144	50,7	4	1,4	0	0	39	5	19	8	123
Thüringen	2.157(379)	843	2,53	1153	54	1120	52,5	33	1,5	28	13	648	21	360	99	831
Düns	380(110)	144	2,67	187	48,6	184	47,8	3	0,8	15	7	10	5	27	17	148
Feldkirch	30.943(901)	13658	2,24	15912	51,3	15120	48,8	792	2,6	287	62	2442	203	13246	1847	8532
Frastanz	6.199(192)	2528	2,43	3144	50,3	2982	47,7	162	2,6	127	30	1006	49	1383	224	2094
Göfis	3.058(337)	1194	2,59	1612	52,1	1560	50,4	52	1,7	33	24	174	27	305	135	1218
Röns	321(223)	118	2,69	161	50,2	154	48	7	2,2	5	4	11	6	28	10	128
Satteins	2.536(200)	991	2,54	1300	51,4	1257	49,7	43	1,7	46	25	137	36	465	107	977
Schlins	2.241(370)	859	2,6	1173	51,7	1123	49,5	50	2,2	47	18	439	34	659	108	833
Schnifis	762(155)	273	2,86	404	51,8	394	50,5	10	1,3	26	14	44	15	78	32	313

Table 4. Calculation of the labor structure: total number of enterprises, relative percentage of employees and enterprises in the three labor sectors.

	Tot. enterprises	Labor in I sector		Labor in II sector		Labor in III sector	
	n.	%		%		%	
		employees	enterprises	employees	enterprises	employees	enterprises
Bludenz	963	2,5	4,6	32,4	10,1	75,7	85,4
Bludesch	118	7,5	7,6	16,7	22,0	56,3	70,3
Bürs	259	2,9	5,8	37,0	5,8	103,4	84,6
Bürserberg	52	4,5	13,5	4,5	11,5	29,8	75,0
Lorüns	15	3,0	13,3	5,3	26,7	27,3	60,0
Ludesch	185	3,1	14,1	22,1	22,7	30,8	63,2
Nenzing	392	2,7	11,7	91,5	14,3	56,9	74,0
Nüziders	305	2,0	4,9	36,9	14,4	40,6	78,4
Stallehr	14	0,0	0,0	27,1	35,7	13,2	57,1
Thüringen	133	2,5	9,8	57,9	15,8	32,1	74,4
Düns	30	8,2	23,3	5,4	16,7	14,7	56,7
Feldkirch	2112	1,9	2,9	16,2	9,6	87,6	87,5
Frastanz	303	4,3	9,9	33,7	16,2	46,4	73,9
Göfis	186	2,1	12,9	11,2	14,5	19,6	72,6
Röns	22	3,2	18,2	7,1	27,3	18,2	45,5
Satteins	168	3,7	14,9	10,9	21,4	37,0	63,7
Schlins	157	4,2	11,5	39,1	21,7	58,7	68,8
Schnifis	61	6,6	23,0	11,2	24,6	19,8	52,5

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4 Methodology and data

4.1 Land use change modeling

Land use, as defined by Di Gregorio (2005), is “the intended management activities underlying human exploitation of a land cover including any arrangements of a certain land cover to produce, change, or maintain it”. Land use and land cover changes are the result of complex interactions between many processes (Verburg et al., 2002). In order to understand these dynamics many models have been developed in the recent decades. Land use change modelling became an important technique to analyze, predict and test the projections in the future of different pathways, allowing to observe and link interacting ecological and social elements (Veldkamp & Lambin 2001). Among the many model typologies, the spatially-explicit models offer the advantage to be able to well represent the land use systems as whole, on a multi-scale and integral manner (Veldkamp & Lambin 2001; Verburg et al. 2002). Stability or instability of land use structure over time is a function of the social, economic and ecological interactions (Verburg et al. 2002). A fundamental difference among the discipline consist in the modelling approach: one group of models is process-based (or structural), the other is statistical-based (or reduced form) (Veldkamp & Lambin 2001). While the model of the first group rely on the assumption that the processes involved in land use change are static, the model of the second are able to handle temporal variability. Despite their essential differences, very often the two families are working complementary, as the structural models are used for hypothesis formulation and the second allow to test the hypothesis with a data limitation (Veldkamp & Lambin 2001). The CLUE model family, belong to a third group, namely the hybrid models (Irwin & Geoghegan 2001). Hybrid models of land use change are therefore composed by two models: the estimation model, which is an empirical spatially-explicit model based on remote sensed data (GIS), and the simulation model, which uses the parameters from the previous to predict the spatial pattern of land use, according to properly built scenarios (Irwin & Geoghegan 2001). Essentially, these models estimate the effects of several parameters or driving factors, on the land use classes, being able to predict dynamically the change in the land use as indicated by the scenarios (Verburg et al. 2002).

4.2 The Dyna-CLUE

The original idea of the Conversion of Land Use and its Effects (CLUE) was developed by Tom Veldkamp and Louise Fresco and published in (1996), in order to simulate land use change using empirically quantified relations between land use and its driving factors in a dynamic modeling context. Later versions were created by Peter Verburg in collaboration with colleagues at Wageningen University and worldwide. For this study the spatially explicit land use model Dyna-CLUE 2.0 (Verburg et al., 2002) in its latest version adapted for regional studies and applications (Verburg & Overmars 2009) was chosen. This model was tested worldwide in a large number of case studies with various aims and different spatial scales and resolutions (e.g. Verburg & Overmars 2007; Cammerer et al., 2013; Xu et al., 2013; Zhang et al. 2013). Verburg and Overmars (2007) tested the model on two case studies localized in a rural landscape in Eastern Netherlands and in a strongly urbanized area in Kuala Lumpur, Malaysia. The trajectories of the land use changes, obtained by testing different scenarios and spatial restrictions in the study areas, are examined in order to underline important spatial issues addressing the policy-makers and especially the proper design of financial subsidies for rural areas in the Netherlands; in the Malaysian case study, the suitability of certain areas to urban sprawls were tested in order to capture and observe the mechanism laying behind urban expansion. Cammerer et al. (2013) implemented the model in the Lech Valley in the district of Reutte (Tyrol-Austria), in order to test the change in the exposure to flood due to land use change in the future and be able to address important issues in the context of risk mitigation and management. Xu et al. (2013) used the CLUE model for a case study in China, in order to introduce a new method in the planning regulations, based on simulated outcomes, in the context of urban sprawl. The model simulates the spatial pattern of land use based on two modules. Combining ecological elements and decision-making they were able to predict, according to three spatial scenarios, three practical development alternatives for the Guangzhou urban sprawl. Zhang et al. (2013) analyzed the possible change in the land use induced by changes in spatial policies in South-Eastern China. Different policy-scenarios were tested – such as "construction land up-hill" and "construction land making room for arable land" – showing the effects of different policy configurations and pushes, aiming also at supporting with this tool the effectiveness in the spatial-planning.

The Dyna-CLUE is a hybrid model, composed by strictly GIS-based parameters and also by parameters which are estimate by the expert such as decision-making, policy, scenarios and trends, drivers of change, etc. The parameters the model can take into account have different spatial and temporal scales, and allow predicting the relations and feedbacks involved in the complexity of the land use change processes. It was initially developed by Veldkamp and Fresco in 1996 and then later improved and modified to fit small scale simulations by Peter Verburg and the University of Wageningen (Verburg et al. 2002; Verburg et al. 2004c; Verburg & Overmars 2009). The Dyna-CLUE was developed to predict land use change according to empirically quantified relations between the land use pattern and its driving factors, combined with a dynamic modelling using a grid-based (raster) datasets for the spatial explicit inputs (Verburg et al. 2002). The model, which might be implemented either on a local scale and/or on a continental level, is built by two distinct modules: a non-spatial land demand module and a spatially explicit allocation procedure (Verburg et al., 2002). The non-spatial module is composed by the future land demand, which is defined by trends, scenarios or other specific model; and the land-use type specific conversion settings, namely conversion elasticities and land-use transition sequences (Verburg et al., 2002). The spatial explicit module is composed by the location characteristics which are defined by the certain location factors (or driving factors) which determines the location specific suitability to a certain land use – the suitability of a certain location to a certain land-use type according to a range of location factors (e.g. accessibility, slope, climate, etc.), is calculated using a binary logistic regression model – and the spatial policies and restrictions, defined by the user according to the local regulations (e.g. built restrictions, Natura 2000, hazard zoning) (Verburg et al. 2002). For each grid cell (location) and simulation year, the most possible land use type is calculated from the combination of the above mentioned components (Verburg et al., 2002).

4.2.1 The theory behind the CLUE

The model is structured into two distinct modules, a spatially explicit part and a non-spatial component. The spatial module is composed by the land use base map in 2006, the driving factors and the restrictions. The non-spatial demand module is composed by the land use conversion settings, namely the matrix and the elasticities, and the land demand, namely the scenarios. The land demand calculates the change in area at the aggregate level for all land use types; on a yearly basis, the model needs to have the relative surface of area covered by each single land use class. This module serves as an input of the spatial module, where the information are translated into a raster-based system and the land is allocated according to the model configuration.

Once the input files are prepared and configured the model calculates with discrete time steps, the most likely change in land use. The land allocation through time is implemented according to this formula:

$$\Pr(P_{i,u}) = P_{i,u} + ELAS_u + ITER_u$$

where:
Pr(Pi,u) for each grid cell *i* the total probability is calculated for each of the land use *u*.
Pi,u is the suitability of the location *i* for the land use *u*.
ELASu is the conversion elasticity for land use u.
ITERu is an iteration variable that is specific to the land use type and indicative for the relative competitive strength of the land use type.

With discrete time steps, the most likely changes in land use are implemented by the model.

1. Determination of all grid cells that are allowed to change. Grid cells that are either part of a protected area or presently under a land use type that is not allowed to change are excluded from further calculation. Also the locations where certain conversions are not allowed due to the specification of the conversion matrix are identified.

2. For each grid cell of the active cells *i* the total probability *Pr(Pi,u)* is calculated for each of the land use types *u*. *ELASu*, the land use type specific elasticity to change value, is only added if the grid-cell *i* is already under land use type *u* in the considered year.

3. A preliminary allocation is made with an equal value of the iteration variable (*ITERu*) (Fig. 17) for all land use types by allocating the land use class with the highest total probability for the considered grid cell. Conversions that are not allowed according to the conversion matrix are not allocated. This allocation process will cause a certain number of grid cells to change land use.

4. The total allocated area of each land use is now compared to the land use requirements (demand). For land use types where the allocated area is smaller than the demanded area the value of the iteration variable is increased. For land use types for which too much is allocated the value is decreased. This procedure tends to balance the bottom-up allocation based on location suitability and the top-down allocation based on regional demand.

5. Steps 2 to 4 are repeated as long as the land demand is not met. When allocation equals demand the final map is saved and the calculations can continue for the next time step.

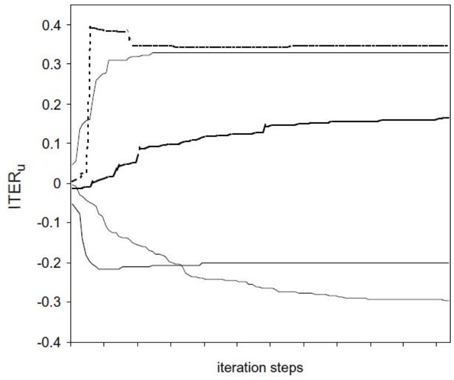

Figure 17. Fluctuation of the iteration variable during the simulation within one time step. This variable expresses the relative competitive strength of each land use type, acting like a multiplier to adapt the allocated land to the land demand given by the scenarios.

4.3 Current land use pattern

The availability of land use information and data is of primary importance (EEA 2002). For the aim of the study was chosen the European CORINE land cover database. CORINE is an acronym standing for "Coordination of information on the environment". The aim of the program of the European Commission are: 1) to compile information on the state of the environment with regard to certain topics which have priority for all the Member States of the Community; 2) to coordinate the compilation of data and the organization of information within the Member States or at international level; 3) to ensure that information is consistent and that data are compatible (EEA 2002). This database provides the availability of landuse maps from the 1990 to the 2012. In order to calibrate the model we chose the 2006 and 2012 land use maps. Older maps show big differences in the surfaces of the respective classes, denoting a change in the criteria of the classification, in the technologies, etc., making the comparison with the most recent maps not possible. In this study, the landuse datasets of the year 2006 and 2012 were generated from the CORINE available maps with a spatial resolution of 100x100 m. The study area was extracted using the geographical information software ArcGIS; the graphic extent is xllcorner 4285324 and yllcorner 2658205, with 409 columns x 371 rows. Seven land use classes were defined with an opportune modification of the Level 2 of the CORINE maps (Tab. 5). A finer classification is not necessarily traduced into a more accurate model output (Cammerer et al. 2013). The seven landuse classes were nominated as follow: urban; industrial, commercial, transport and mining units; agricultural land; forested land; pastures and grasslands; bare land; water bodies and wetlands. The mine, dump and construction sites were assimilated into the Industrial, commercial, and transport units due to the relatively low surfaces of mining, dumping and construction sites which does not play a big role in the overall landuse equilibrium in the studied area.

According to this nomenclature, the land use classes have to be coded in order to be read by the model (Fig. 18). Therefore, to each class was assigned a value from 0 to 6: urban “0”; industrial, commercial and transport units “1”; agriculture “2”; forest “3”; grassland “4”; bare land “5”; water “6”. The no-data cells were classified with the value “-9999”. After the classification, the land use map of 2006 was further processed in order to obtain the file needed for the modelling process. Each land use class was then extracted with ArcGIS in order to have one map for each category, with the respective value for the cells where that class is present, while to the remaining cells was given the no data value of “-9999”. Hence, the land use map of 2006 and the extracted land use classes of 2006 were then converted to ASCII files which can be handled by the Dyna-CLUE. The 2006 landuse ASCII was named according to the model requirements as “*cov_all.0*”, as well as the ASCII files from the extracted landuse classes which were named as “*cov1_x.0*”, where *x* stands for the respective value of each landuse type, ranging from 0 to 6.

Table 5. Classification and coding of the land use classes based on the modified LABEL_2 from CORINE database.

Code	Aggregated class	Label 2 [CORINE]
0	Urban	Urban fabric
0	Urban	Urban fabric
0	Urban	Artificial, non-agricultural vegetated areas
0	Urban	Artificial, non-agricultural vegetated areas
1	Industrial (or commercial)	Industrial, commercial and transport units
1	Industrial (or commercial)	Industrial, commercial and transport units
1	Industrial (or commercial)	Industrial, commercial and transport units
1	Industrial (or commercial)	Industrial, commercial and transport units
1	Industrial (or commercial)	Mine, dump and construction sites
1	Industrial (or commercial)	Mine, dump and construction sites
1	Industrial (or commercial)	Mine, dump and construction sites
2	Agriculture	Arable land
2	Agriculture	Arable land
2	Agriculture	Arable land
2	Agriculture	Permanent crops
2	Agriculture	Permanent crops
2	Agriculture	Permanent crops
2	Agriculture	Heterogeneous agricultural areas
2	Agriculture	Heterogeneous agricultural areas
2	Agriculture	Heterogeneous agricultural areas
2	Agriculture	Heterogeneous agricultural areas
3	Forest	Forests
3	Forest	Forests
3	Forest	Forests
4	Grassland	Pastures
4	Grassland	Scrub and/or herbaceous vegetation associations
4	Grassland	Scrub and/or herbaceous vegetation associations
4	Grassland	Scrub and/or herbaceous vegetation associations
4	Grassland	Scrub and/or herbaceous vegetation associations
5	Bare land	Open spaces with little or no vegetation
5	Bare land	Open spaces with little or no vegetation
5	Bare land	Open spaces with little or no vegetation
5	Bare land	Open spaces with little or no vegetation
5	Bare land	Open spaces with little or no vegetation
6	Water	Inland wetlands
6	Water	Inland wetlands

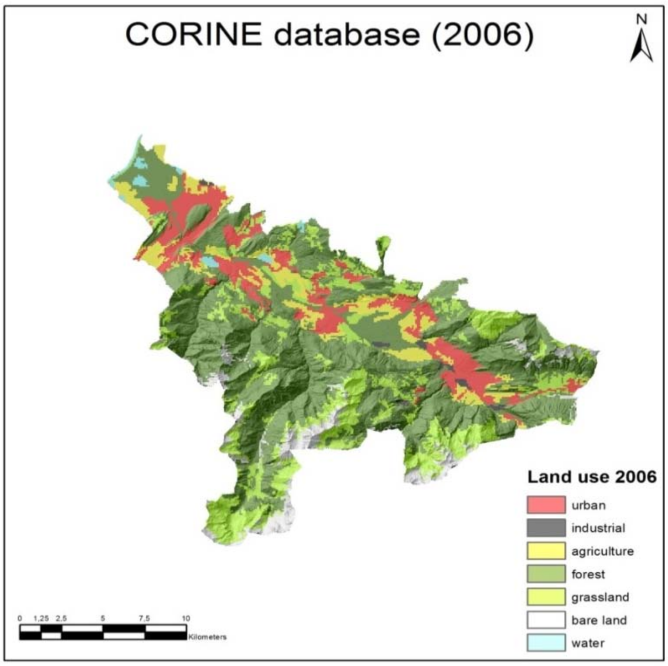

Figure 18. Land use map 2006 elaborated from CORINE database.

4.4 Driving factors

Land use system are the result of complex interactions and feedbacks, being at the interface between multiple social and ecological systems (Verburg et al. 2002). Due to these interconnections land use systems can be assimilated to ecological systems (Verburg et al. 2002). This basic assumption allow the land use change modelers to borrow the concepts that have been developed in the ecological systems simulations, offering the chance to represent complex non-linear systems where social elements and ecological processes are involved (e.g. Adger 2000). In his study, Adger compares and links the social to the ecological resilience. Resilience expresses the speed of recovery of a system from one or more disturbances. Thus, Adger observed that the social and ecological systems behave in the same way when affected by disturbances. In the same way as a forest recovers after the fire as a function of its structure, so the land use and land use changes are the function of ecological, social, institutional, etc. structures (Verburg et al. 2002). According to these characteristic of land use systems, land use change modeling must meet certain requirements in order to be able to represent the reality: the simulation should take into account the multiple spatial scales; the drivers of changes have to be divided into quantitative- and location-drivers of change; sudden alteration in the drivers should not directly affect the land use pattern as a consequence of its stability and resilience; the model framework should allow interactions between locations and feedbacks between different levels of organization (Verburg et al. 2002).

In order to assess the impact of potential future development of the environment, economy and society, a deeper understanding on the determinants of the spatial configuration of land use is necessary (Verburg et al. 2004a). Land use changes are the results of many interacting processes (Verburg et al. 2002), and are driven by a wide number of factors and their feedbacks (Veldkamp &

Lambin 2001). The history of the land use changes can be well explained by several elements: the location environmental bio-physical properties (e.g. climate, morphology, soil, etc.), the accessibility to land (e.g. spatial policies, distance from facilities) and the socio-economical characteristics (e.g. population density, industrial and other activities, etc.) (Verburg & Veldkamp 2002; Verburg et al., 2004a; Verburg et al., 2004b). The land use pattern at a given time is explained by a set of parameters, or explanatory variables. These factors are selected by the user according to the location characteristics and are based on interdisciplinary understandings of land use change determinants. Land use conversions are expected to take place at locations that show the highest "preference" for a specific land use type at a given time (Verburg et al. 2002). In other words, mathematically speaking, the preference is empirically estimated through a binomial logit model, or Binary Logistic Regression. The influence that each explanatory variable (independent variables) has on the actual land use pattern (dependent variable) is quantified obtaining a set of coefficients (β) (Verburg et al. 2004a). The coefficients express the relative impact of each single bio-physical or socio-economical factor on the land use type of a certain location. The statistical procedure of this method will be further addressed in the following pages.

Using ArcGIS, the selected variables were rasterized with the same spatial resolution as the land use maps (100x100 m). Due to the big heterogeneity of the database and the wide source of data, the pixels were not perfectly matching between one raster layer and the other. Since the presence of these overlapping errors it was difficult to make sure that the cells actually match among the layers, therefore it was not possible to simply convert the raster files to asci files and then build the vector for the statistical processing. For this reason we convert the map of landuse 2006 into point features, where each pixel is represented by one point. Then all the values stored were merged (tool: Multiple values to point) into the respective points, ending up with a huge attribute table already arranged to be imported and processed by SPSS.

The table that follows (Tab. 6) represents the set of potential driving factors we chose, with the respective source/dataset from which they were derived. The number will be reduced during the following step through statistical analysis, since the CLUE can only handle maximum 30 driving factors. The driving factors can be of two types: dynamic factors (e.g. population, labor structure, climate), which have different values at each year over the simulation period; constant factors (e.g. altitude, soil), which do not change over time (Verburg & Veldkamp 2002). It was decided to use only static variables, therefore also the population density was considered to be stable during the simulated time range. For example, the population density showed a big increase during the 60s and 70s, but then it stabilizes on the actual values with little or no variations in the last two decades, thus we considered it as a static parameter. Also the climatic variables were considered static due to the short modelled time period, in which we assumed no significant climatic changes. This approach was chosen, partly for simplicity and data availability reasons, but also because given the short simulated time span (25 years) changes in these variables are likely to be negligible (Price et al. 2015). No neighborhood interactions, or enrichment factor (Verburg et al. 2004d), were taken into account in this study.

After we selected through the statistical analysis the driving factor to be entered in the model, we proceed with the conversion of the raster maps representing the spatial configuration of each driver, into ASCII format which can enter the CLUE model. The files were then named according to the model requirements as "*sc1grx.fil*", where *x* stands for the number that identifies one explanatory variable and it ranges from 0 to 29. For more details on the driving factors sources and how they were derived, please see the Appendix A.

Table 6. Initial series of driving factors or explanatory variables, how they were derived and source. The list was afterwards thinned by a preliminary correlation analysis in order to exclude the auto-correlation within the variables. From this list were then created thirty variables to enter the Binary Logistic Regression model

DRIVER	**UNIT**	**SOURCE**
Solar radiation	WH/m2	DEM
Elevation	m	DEM
Slope	Deg (0-90°)	DEM
Aspect	Compass deg (0-360°)	DEM
Precipitation (1961-1991)	mm	Austrian Hydrological Atlas
Temperature (1961-1991)	° C - 6 categories	Austrian Hydrological Atlas
Geology	3 categories	Austrian Hydrological Atlas
Standard soil classification	5 categories	Austrian Hydrological Atlas
Soil permeability	4 categories	Austrian Soil Map
Distance form Railway Station	Cost Distance	VoGis
Distance form Highway	Cost Distance	VoGis
Distance from Street	Cost Distance	VoGis
Distance from School	Cost Distance	VoGis
Distance from City	Cost Distance	VoGis
Distance from Hospital/ER	Cost Distance	VoGis
Population density	persons/km² (*)	Statistik Austria 2011
Private housing	% (*)	Statistik Austria 2012
One-person private	% (*)	Statistik Austria 2012
Two-persons private	% (*)	Statistik Austria 2012
Three-persons private	% (*)	Statistik Austria 2012
Four-persons private	% (*)	Statistik Austria 2012
Multi-persons private	% (*)	Statistik Austria 2012
Activity rate	% (*)	Statistik Austria 2012
Labor force	% (*)	Statistik Austria 2012
Unemployment	% (*)	Statistik Austria 2012
Employees in the I sec	% (*)	Statistik Austria 2011
Employees in the II sec	% (*)	Statistik Austria 2011
Employees in the III sec	% (*)	Statistik Austria 2011
Enterprises in the I sec	% (*)	Statistik Austria 2011
Enterprises in the II sec	% (*)	Statistik Austria 2011
Enterprises in the III sec	% (*)	Statistik Austria 2011
Commuters	n. of persons (*)	Statistik Austria 2012

(*) *Values are referred per each municipality*.

4.4.1 Statistical analyses

Within the wide set of potential driving factors we performed a preliminary correlation analyses with the statistical software SPSS, in order to make a selection and avoid biases generated from spatial autocorrelation (Overmars et al., 2003). Hence, a number of nineteen variables were chosen to enter the Stepwise Binary Logistic Regression model performed with SPSS; variables like geology, soil and temperature had to be classified respectively through three, five and six categories. The logistic regression is commonly used to analyze the spatial relations between land use and its driving factors. Performing this statistical method we could identify those factors that have the highest influence, and quantify it, on the land use patterns (Overmars et al. , 2003; Verburg et al., 2002).

A logistic regression was run for each land use class. Land use conversions are expected to take place at locations that show the highest "preference" for a specific land use type at a given time (Verburg et al. 2004a). The preference is calculated as follows:

$$R_{i,u} = a_u X_{1,i} + b_u X_{2,i} + \cdots + z_u X_{n,i}$$

where:

R is the preference to allocate location i to land use u.

$X_{1,2,\ldots,n}$ are the explanatory variables or driving factors, that have an influence on the location i.

a_u, b_u and z_u are the relative impact of these factors on the preference for land use u.

Since the preference cannot be measured directly, it has to be estimated as a probability. The binomial logit model is a dichotomous statistical model functioning as follows: convert the location i into land use type u (0) or not (1) (Verburg et al., 2002). The relations between land use and its driving factors are therefore evaluated through the following expression, which relates the probability of a certain grid cell to be allocated to a land use type according to the set of explanatory variables that was chosen:

$$log\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_n X_{n,i}$$

where:

P_i is the probability of a grid cell for the occurrence of the considered land use type on location i.

$X_{1,2,n}$ are the explanatory variables or driving factors, that have an influence on the location i.

β_0 is the constant for the considered land use type.

$B_{1,2,\ldots,n}$ are the coefficients of the driving factors.

The logistic regression model was built according to the forward stepwise procedure, with a probability threshold of enter the model of 0.01 and 0.02 for removal form the model. This statistical analysis was performed for each land use type against the factors we believed may better describe the considered land use category for the modelled period 2006-2030. The variables that have no significant impact on the land use pattern are excluded from the final equation by the model.

In order to assess the goodness of fit of the statistical model, a ROC analysis was performed, providing a measure of how good – up to which extent the model is able to represent the reality – is our statistical model. The relative operating characteristic method (ROC) is able to measure the quality of the predictors, namely the relation of the explanatory factors and the land use. The ROC characteristic is a measure for the goodness of fit of a logistic regression model (Pontius & Schneider, 2001). A completely random model gives a ROC value of 0.5 while a perfect fit results in a ROC value of 1.0. The suitability model was the same in all scenarios (e.g. Price et al. 2015).

Based on the regression results the Dyna-CLUE built for every year of simulation one probability map for each land use class. The regression results are written in the allocation file, which contains the *β* values and the constant of the binary logistic regression. The land allocation file was converted into a text file and named "*alloc1.reg*".

4.5 Spatial policies and scenarios

4.5.1 Restrictions policies and hazard zoning

Spatial policies and restrictions are acknowledged to be decisive concerning the future development of the land use. In fact they might represent a constraint or an incentive to the development of certain spatial arrangement in a designated area (Holub & Fuchs 2009). For instance, it is stated in the Regional Planning Act of the State of Vorarlberg (*Vorarlberger Raumplanungsgesetz)* that the natural or close-to-nature areas as well as the drinking water reserves have to be preserved (§ 2 (3) c) (Land Vorarlberg 1996). Moreover, it is prescribed by this law that building is forbidden in the areas prone to natural hazards like flooding, avalanches, rock fall, landslide, etc., or building is allowed only if certain technical protection measures are implemented (§ 13 (2) a, § 13 (3)), because by law the living or working space has to be protected from natural hazards (§ 2 (2) a). It is also advisable to keep free from any settlements the areas prone to natural hazards (§ 18 (5)). In this set of laws and regulations there are two levels which define the land allocation and utilization: the regional planning (*Landesreaumpläne*) and the local planning (*Raumplannung durch die Gemeinden)* which is implemented in each municipality, defining the spatial zonation (e.g. housing, commercial and industrial, etc.) in the municipal territory (*Flächenwidmungsplan*) (Land Vorarlberg 1996).

Dealing with torrential hazard, the tool which defines the zonation and regulates the spatial planning is the hazard zones plan (*Gefahrenzonenplan*) set in the Austrian Forest Act (*Forstgesetz*) in 1976, which has to identify the hazard-prone areas (Republik Österreich 1975). The hazard planning defines zones which are endangered by natural processes and it is compiled by the Austrian Service for Torrents and Avalanche Control (WLV). The torrential and avalanche hazards are separated into red and yellow zones. In the red zone the hazard is so high that (new) settlements are not allowed or are allowed only with specific technical protections. The yellow zone might be used for settlements or transportation network with certain conditions and limitations. Other types of hazards, like rock-falls and landslides, are designated by brown zones. The hazard plan defines two more zones: the blue zones, which have to be kept free for technical or biological protection measures, and the purple zones, which already present natural protection characteristics. These hazard zones are built for a design event with a return period of 150 years (WLV 2013; Fuchs et al. 2015).

Moving downslope, in the lower part of the catchments the support tool for planning is the hazard zonation by the Austrian Federal Water Engineering Administration (BMLFUW) (Fuchs et al. 2015). The zonation defines three areas: (1) areas within the water body area flooded every 30 years (HQ30) – to be kept free from protective measures or require special management interventions, (2) areas threatened during a design event occurring statistically every 100 years (HQ100) and (3) areas that could be affected if an event with a return period up to 300 years occurs (HQ300). The latter are also called residual risk areas since they might be flooded after a failure of the protection structures (Fuchs et al. 2015). Within these three groups are also defined red and yellow zones, which have the same valence as the WLV hazard zones: the red zone, or no building zone, is not suitable for permanent settlement or transport purposes; those areas managed for run-off or retention purposes are defined as red-yellow zone; the remaining areas up to the HQ100 perimeter are suitable only under certain conditions and limitations and are identified as yellow zone; blue zone are areas demanded by the water authority for technical protection purposes.

The natural protected areas were derived from the VoGis database. These areas include Natura 2000, European and local landscape protected zone, European and local natural areas, etc.

From these datasets – VoGis (e.g. Natura 2000, National Parks, etc.), the hazard zonation from the Austrian Service for Torrent and Avalanche Control (WLV) and the zonation by the Austrian Hydraulic Engineering Administration (BMLFUW) – we created three restriction maps using the software ArcGIS, with different restricted zones, in order to test the effects that spatial policies have on the predicted land use arrangements. The first map, named Restricted Light includes only the Natural Protected areas, thus completely and fully implemented as a building ban. The second map was named Restricted Medium, it represents the actual state regarding the restriction configuration, meaning that it is nowadays taken into account during the spatial planning phase. The hazard zonation is however not legally binding regarding to building bans (Holub & Fuchs 2009). This map was built adding up the Natural Protected areas with the Red Zones by the WLV and the HQ30 by the BMLFUW. The third map, named Restricted Heavy, includes the Red and Yellow Zones by the WLV, the HQ100 by the BMLFUW and of course the Natural areas. This map represents so to say the best case scenario from our point of view, where the spatial development has to stick to a bigger restricted area. The restriction maps were rasterized with a spatial resolution of 100 m. The maps were classified assigning the value "-9998" to the restricted cells and the value "0" to the non-restricted remaining cells. The no data cells were classified as "-9999". The maps were converted into ASCII format and named as "*region_nopark1.fil*", representing the no restriction map; the three different restriction intensities were named as "*region_park –a –b –c"* (Fig. 19).

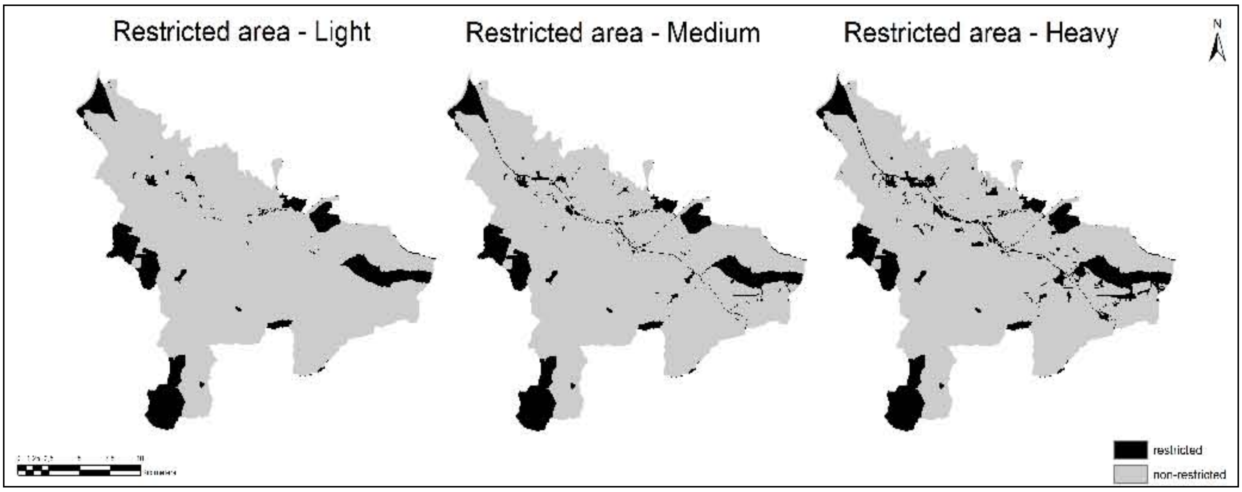

Figure 19. Restriction configurations that were tested in the simulations – also a no-restriction were generated to test the spatial development without any constraints. The light restriction includes only the natural areas such as Natura 2000, National and Local Parks, EU-protected areas, etc. The medium restriction includes the natural areas, plus the hazard zones: red zones by the WLV and the HQ30 by the BMLFUW. The heavy restrictions include the natural protected areas, the red and yellow zones by the WLV and the HQ100 by the BMLFUW.

4.5.2 Spatial planning scenarios

Before starting the simulation with the Dyna-CLUE we need to calculate and build the land use requirements, namely the land demand files. The demand is calculated at aggregate level as part of a specific scenario. These files are needed to give the model the magnitude of the land use change in the simulated time period. The preparation of these files is made outside the CLUE, based on a wide range of methods.

In order to calibrate the model we used generate a baseline scenario using the available landuse maps from 2006 and 2012, calculating the surfaces in the missing years with a simple regression technique. Regarding the future projections, we chose the already available spatial planning scenarios by the ÖROK, Austrian Conference on Spatial Planning (ÖROK, 2008). These scenarios are based on the IPCC-SRES [1] scenarios based on European megatrends, which are long-term processes with impacts on all societal groups and regions. These trends were identified and delineated by some parameters or driving forces: institutional change, population dynamics, society/consumption habits, economy, energy (fossil, renewable), transport mobility, agriculture and forestry, tourism and environment. The Austrian Conference on Spatial Planning generated four integrated scenarios for the spatial and regional development of Austria in the European context until 2030. The participatory analysis of these European-wide and global-wide themes/factors within the different stakeholders,

[1] IPCC stay for Intergovernmental Panel for Climate Change and the first assessment report was compiled in 1990. The IPCC-SRES scenarios were developed in order to represent the range of driving forces behind the actual climatic change, with the aim of tracking the trends of future climatic projections according to several socio-economic and environmental parameters and their complex interactions. The understanding of these dynamics should be helpful for the implementation of the right decision in the policy-making contest. The scenarios can be grouped into six families, and the storylines turn around future market development and fossil fuel consumptions.

allowed generating the four scenarios adapted to the Austrian context: “Overall growth”, “Overall competition”, “Overall security” and “Overall risk”.

4.5.2.1 Scenario descriptions

The key driving factors influencing land use changes that were identified by the IPCC, are population, global market and economy, energy and land utilization (ÖROK 2008). The storylines, that describe possible socio-economic future changes, were developed and defined across two main axis (Fig. 20): globalization vs regionalization, and free market-oriented vs policy and planning intervention (Price et al. 2015).

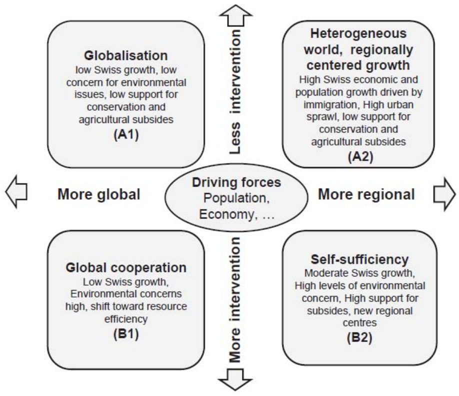

Figure 20. Scenarios storyline axes from Price et al. 2015.

Overall Growth. The driving forces of the spatial development named above are strongly increasing in the time span. The increased demand for energy and the strongly market-oriented society lead to a building pressure on not-built land plots. Therefore, this scenario is the most extreme under an urbanization point of view.

Overall Competition. The driving forces grow strongly, but the market is assumed to react in time to scarcities and avoid crisis. The pressure on the land is high in the growth zones (e.g. urban and industrial areas), while other regions are confronted with migration and population shrinking.

Overall Security scenario is characterized by a moderate growth of most of the driving forces. In those regions suitable for forestry and farming the pressure will increase due to higher demand from renewable energy (e.g. biomass). Due to higher prices of energy and fuel, thus high mobility costs, the urban agglomeration and centralization are favored.

Overall Risk shows similar driving forces dynamics as the previous scenario, but no mechanism against sudden energy scarcity are developed. The energy prices rise quickly with no countermeasures taken by the market. The spatial development is determined by more densely built-up areas and more intense exploitation of natural resources for energy purposes.

4.5.2.2 Scenario quantification: downscaling process

The Austrian scenarios have to be as well adapted to the Ill-Walgau spatial pattern due to the peculiarities of this area, which is not completely comparable to the national distribution. The IPCC-derived scenarios include socio-economic data and climatic trends, which are defined by the storylines. The description of the storylines is very much helpful to make consistent assumptions during the downscaling process (van Vuuren et al. 2007). The downscaling was performed in order to obtain the quantification of the percentage variations, thus in hectares, of each land use class over the simulated time span. In climatology the downscaling process is a procedure to take information known at large scales to make whether predictions at small scales, particularly at the surface level (Widmann et al. 2003). Thus in this case, it was needed to take the information about the relative land variation generated on a coarser scale, to be able to predict the land variations on the considered study area. Since as I already mentioned, the differences between the national and the local level are significant, we could not simply assume a direct proportionality in the trends (van Vuuren et al. 2007; van Vuuren et al. 2010). Hence, assuming a partial convergence within the two units – which means that the local outcome depends for a certain extent to the national pathways – we performed a scenario convergence in order to generate a plausible outcome at the local level (van Vuuren et al. 2010). The Tab. 7 summarizes the calculations steps to obtain the surface variation throughout the years.

Table 7. The table show the step of the calculation done to obtain for each land use class the variation percentage, hence the surface(ha), within the considered time range 2006-2030.

1	***r***	***[% Aut]/[% IllWalgau]***	Rate between the national and the local percentage of each land use class (national/local).
2	***f***	***[δ%_ÖROK]/r***	Downscaling factor for change to the local spatial distribution.
3	***δ%_IllWalgau***	***[δ%_ÖROK] – f***	Adapted for the area variation in percentage 2006-2030.

The δ% obtained was then multiplied with the total hectares in 2006; the variation in hectares was then added to the surface in 2006 to obtain the surface in ha in 2030, for each scenario and land use class. Since the demand file has to express on a yearly basis the surfaces of each class, the surfaces in the intermediate years were derived with a simple regression. The scenario files, which are composed by seven columns (land use classes) and 25 rows (2006-2030), were converted into text format and named "*demand.inx*", where *x* ranges from 1 to 5.

4.6 Matrix, elasticities and main settings

4.6.1 Land use specific conversion settings: matrix and elasticities

The land use conversion settings lead the dynamics of the simulation, using two sets of parameters: conversion elasticities and land use transition sequences, namely land use matrix. The conversion elasticities are related to the degree of reversibility to change of each land use type. It is expressed by a dimensionless value ranging from 0 (easy conversion) to 1 (irreversible conversion) for each land use (Verburg & Veldkamp, 2002). The conversion elasticity is thus the approximated measure of the cost of conversion of one land use class to another; the cost can be either monetary or institutional, and it affects the probability of a certain location (pixel) to remain under the current land use type (Verburg & Overmars, 2009). For instance, land use classes with high initial capital investment are less likely to be converted to another type (e.g. wine-yard), while land uses with low initial investment might easily change towards another category if the general conditions favor that change (e.g. grassland to wine-yard). The closer to zero, the easier is the conversion; and vice-versa, the closer to one the harder is the conversion (e.g. Verburg & Veldkamp 2002; Xu et al. 2013). This parameter is applied only to those locations where the considered land use type is found at time *t* (Verburg & Overmars 2009). The elasticities are specified in the line 11 of the *main* file and it can be edited directly through the user interface in order to have the model calibrated (Verburg & Veldkamp 2002).

The second file is the land use conversion matrix, being an A x A matrix with A equal to the number of land use categories. The matrix indicates the sequence of possible or not possible conversions among the classes. In our case we have seven land use classes and the matrix has 7 rows x 7 columns. When the conversion is allowed, we assigned the value “1”; when it is not allowed, we assigned the value “0”. The matrix was converted into a text file named “*allow.txt*”.

The *main* file is built by the user and contains the model main settings such as the number of land use classes, the number of driving factors used, the elasticity values, total years of the modelling, graphic extent and other switches (e.g. iteration variable). This file was named “*main.*1”. For more detail please see the Appendix B.

4.7 Model calibration and validation

In order to calibrate all the input parameters of the model, the maps of CORINE land use in 2006 and 2012 were used. The calibration runs were performed running the model from 2006 to 2012. The scenario that was chosen was simply a regression calculation, using the surfaces in 2006 and 2012, deriving the values in the missing years. The simulated outputs in 2012 were then confronted with the 2012 “reality map” provided by CORINE. Before proceeding to the statistical validation, a visual validation were performed, confronting the output 2012 map, with the CORINE 2012 and aerial pictures (ortho-photos) of 2006 and 2012. The tool that was used is the *Tabulate Area* ArcGIS tool (*Spatial Analyst*), which put in a tabular comparison the simulated output and the “real” map (Pontius et al. 2008). The Tab 8 shows where the pixels were allocated correctly and where they were spread through other classes other than the right class according to the CORINE 2012 land use map.

From these tables, the accuracies for each land use class could be calculated. There are three types of accuracies to be calculated: the Producer, the User and the Overall Accuracy. The Producer Accuracy is calculated through the rate between the correctly allocated pixels of the simulation output with the pixels in the “reality” map in 2012 (*Sum Corine*). The User Accuracy is the rate between the correctly allocated pixel of the simulated output and the sum of the overall allocated pixels in the considered land use class (*Sum model*). The Overall Accuracy is calculated through the rate between the overall correctly allocated pixels among all the classes (Sum *Diagonal*) and the total number of pixels belonging the study area (33 951).

Table 8. Example of tabulate area, with correctly allocated pixels in the diagonal and the not-correctly allocated pixels.

		Corine classification (2012)							
		URB	IND	AGR	FOR	GRASS	BARE	WAT	
Simulated	URB	***Correct***	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	**Sum model**
	IND	*Non-correct*	***Correct***	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	**Sum model**
	AGR	*Non-correct*	*Non-correct*	***Correct***	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	**Sum model**
	FOR	*Non-correct*	*Non-correct*	*Non-correct*	***Correct***	*Non-correct*	*Non-correct*	*Non-correct*	**Sum model**
	GRASS	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	***Correct***	*Non-correct*	*Non-correct*	**Sum model**
	BARE	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	***Correct***	*Non-correct*	**Sum model**
	WAT	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	*Non-correct*	***Correct***	**Sum model**
		Sum Corine	**Sum Corine**	**Sum Corine**	**Sum Corine**	**Sum Corine**	**Sum Corine**	**Sum Corine**	**SUM CORRECT**

Through this procedure the model's parameters could be calibrated in order to obtain the most close-to-reality as possible outcome. The parameters that were edited through the model interface were the elasticities, the iteration variables and the conversion matrix – staying of course inside the domain of the bio-physical plausibleness and legal constraints given by the law. This procedure was repeated using the four different restriction configurations, namely No Restrictions, Light, Medium and Heavy Restrictions.

4.8 Exposure analysis

Overlapping the outcomes of the simulation with the actual hazard zonation (for more details please see *"4.5.1 Restriction policies and hazard zoning"*), it was possible to perform the exposure analysis in 2030. Having four spatial scenarios and four restriction configuration to test, the simulated maps in 2030 were sixteen. The analysis was performed counting the pixels which lay under the mask of the different hazard zones. The cross-check procedure aims at assessing the amount of land falling under the hazard zones, defined by the WLV and the BMLFUW. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask. A number of four hazard zones were defined, with different surfaces: the red zones, the yellow zones, the HQ30 and the HQ31-100. The total amount of the surface under hazard was 1402 ha (red and yellow zones, HQ100).

4.9 Model sensitivity analysis

The land use pattern at a given time is explained by a set of parameters, or explanatory variables. These factors are selected by the user according to the location characteristics and are based on interdisciplinary understandings of land use change determinants. Land use conversions are expected to take place at locations that show the highest "preference" for a specific land use type at a given time (Verburg et al. 2002).

In order to test the sensitivity of the model to the set of driving factors, two additional runs were made. From the results of the binary logistic regression were excluded the variables expressing the labour structure (enterprises and employees in the three sectors) and the five variables expressing the soil classification adopted from FAO. The drivers left in the equation are: population density, private housing percentage, distance to the station, distance to the city, yearly precipitation, distance from the school, distance from the street, aspect, elevation, the four categories of geology (lime stone, detrital formation, alluvial formation), and the six temperature ranges from – 2° to 10° C annual average.

The aim of this analysis is to test how a different set of driving factors might influence the model outcomes, and therefore how the incorporation of the explanatory drivers of change affects the results. The quality of the dataset and the way these data area expressed – results of the logit function – has still big gaps to be filled and a number of uncertainties are present (Verburg et al. 2013). The test runs were performed with the two opposite extreme scenarios *Overall Growth* and *Overall Risk*, using the No Restriction configuration.

Most important in order to assess the impact of the driving factors on the simulated outcomes, is the location of the variation, namely where the changes from the two runs are happening, where are the hotspots and which classes are the most involved and why. A new raster expressing this change was created with a simple expression in the raster calculator:

*[("Raster_30drivers" * 10) + 100] + "Raster_19drivers" = "Change_raster"*

With visual the help of the map obtained through this equation, it is possible to analyse the changes.

5 Results and Discussion

5.1 Statistical analysis

5.1.1 Preliminary drivers selection: correlation analysis

Within the wide set of potential driving factors we performed a preliminary correlation analyses with the statistical software SPSS, in order to make a selection and avoid biases generated from spatial autocorrelation (Overmars et al., 2003). The potential drivers are thirty-two and they might be subdivided into three groups:

1. Bio-physical factors
2. Accessibility factors
3. Socio-economic factors

Bio-physical factors

The autocorrelation analysis of the bio-physical drivers (Tab. 9) showed that the *Solar radiation* was correlated with the *Aspect*, as one may expect. Therefore, it was decided to drop out the *Solar radiation* since the *Aspect* affects the *Solar radiation* and not vice-versa. Also the *Soil permeability* showed a spatial correlation to the *Geology* and to the *Standard soil classification*, that means that the permeability of the soil is mainly driven by both geology and soil typology.

Table 9. Bio-physical factors. “0” dropped out; “1” used for the LOGIT model. “” and “**”shows which factors are correlated to each other, thus they were dropped out.*

DRIVER	UNIT	SELECTION	
Solar radiation	WH/m2	***0***	*
Elevation	m	***1***	
Slope	Deg (0-90°)	***1***	
Aspect	Compass deg (0-360°)	***1***	*
Precipitation (1961-1991)	mm	***1***	
Temperature (1961-1991)	° C - 6 categories	***1***	
Geology	3 categories	***1***	**
Standard soil classification	5 categories	***1***	**
Soil permeability	4 categories	***0***	**

Accessibility factors

The autocorrelation analysis of the accessibility drivers (Tab. 10) showed that the *Distance from the Highway* is partially correlated with the *Distance from the Street*, thus the *Distance from the Highway* was dropped out, because the state road and the highway have follow mostly a parallel route. *Distance from Hospital/ER* showed a correlation with the *Distance from City*, thus it was eliminated – main hospitals are in fact located in the two main cities, Bludenz and Feldkirch.

Table 10. Accessibility factors. "0" dropped out; "1" used for the LOGIT model. "" and "**"shows which factors are correlated to each other, thus they were dropped out.*

DRIVER	UNIT	SELECTION	
Distance form Railway Station	Cost Distance	**1**	
Distance form Highway	Cost Distance	**0**	*
Distance from Street	Cost Distance	**1**	*
Distance from School	Cost Distance	**1**	
Distance from City	Cost Distance	**1**	**
Distance from Hospital/ER	Cost Distance	**0**	**

Socio-economic factors

The autocorrelation analysis of the socio-economic drivers (Tab. 11) showed that the parameters expressing the private housing distribution and characteristics were correlated each other; therefore it was decide to keep in the final model only the general parameter expressing the percentage of the private housing in the municipality. The drivers regarding labor, employment and labor structure pass through a selection process, which left to be entered in the model the labor structure and characteristics, namely the number of enterprises and employees in the three labor sectors.

Table 11. Socio-economic factors. "0" dropped out; "1" used for the LOGIT model. "" and "**"shows which factors are correlated to each other, thus they were dropped out.*

DRIVER	UNIT	SELECTION	
Population density	persons/km²	**1**	
Private housing	%	**1**	*
One-person private	%	**0**	*
Two-persons private	%	**0**	*
Three-persons private	%	**0**	*
Four-persons private	%	**0**	*
Multi-persons private	%	**0**	*
Activity rate	%	**0**	**
Labor force	%	**0**	**
Unemployment	%	**0**	**
Employees in the I sec	%	**1**	**
Employees in the II sec	%	**1**	**
Employees in the III sec	%	**1**	**
Enterprises in the I sec	%	**1**	**
Enterprises in the II sec	%	**1**	**
Enterprises in the III sec	%	**1**	**
Commuters	n. of persons	**1**	

5.1.2 Binary Logistic Regression

A number of nineteen variables were chosen to enter the Forward Stepwise Binary Logistic Regression model performed with SPSS; variables like geology, soil and temperature had to be classified respectively through three, five and six categories. The probability level for entry in the model is 0.01 and the probability for exit 0.02. The Tab. 12 shows the results of the Stepwise Binary Logistic Regression model and of the ROC analysis which is a measure for the goodness of fit of a logistic regression model (Pontius & Schneider, 2001). A completely random model gives a ROC value of 0.5 while a perfect fit results in a ROC value of 1.0. The suitability, namely LOGIT model, model was the same in all scenarios (e.g. Price et al. 2015).

Among the selected explanatory variable we exclude manually those drivers that logically have no influence on the considered land use class, while the remaining part of the selection and evaluation of the impact was given to the statistical model. Only the variables with higher impact where selected by the model ($p < 0.01$). The odds (*Exp(β)*) of the model might be interpreted as the change in the probability for the considered event with an increase in one unit in the related driver, while the other drivers are considered to be constant (Cammerer et al. 2013a). *Exp(β)* expresses the change in the odds for the dependent variable, after one unit change in the independent variable: when Exp(β) > 1 the probability increases upon an increase in the independent variable value; when *Exp(β)* < 1 the probability decreases (Verburg et al., 2002). For more details on the method please see section 4.4.1.

Urban. The variables that were excluded manually are those bio-physical factors having no influence on whether a location is suitable for building houses. The manually excluded factors are *Precipitation, Geology* (3 categories), *Soil standard classification* (5 categories) and *Temperature* (6 categories). These were considered to have no or very little influence on the urban class. The variables excluded by the model are: *Enterprises i* and ii sectors, *Private housing*, *Distance from the station, Distance from the city, Distance from the school, Distance from the street* and *Aspect*. The reason why *Distance for the city* was excluded was probably due to the fact that in this driver only the main cities of Feldkirch and Bludenz were considered, even though the valley bottom shows a quite densely and fine urban texture. Therefore the statistical model found this driver to be non-influent for the urban class. The labor characteristics (*Employees i, ii, iii,* and *Enterprises iii*) have a negative impact on the urban class. The employees in the first sector (e.g. agriculture and forestry) have a stronger negative impact – the probability of occurrence of the urban decreases by a 27% upon the increase of one unit of the employment in the first sector (one % point). In fact, normally farms and forest-related businesses are located outside the cities. The more employees in the second and third sector influence negatively the presence of the urban class (- 2%). The elevation and the slope affect also negatively the probability to have urban settlements, respectively by a – 1% and – 3%, whereas the population density affects positively the occurrence of the same land use class (+ 0.001%).

Industrial. This class is affected positively by the share of the employees and enterprises in the second sector (respectively + 3% and + 4%). The increasing in the distance from the street and the elevation affect slightly negatively this class (- 0.1 and – 1% respectively), while the distance from the station and from the city show almost no impact. The slope was dropped out from the model.

Agriculture. Only the share of employees in the first sector affects positively the occurrence of the agricultural class (+ 9%). The precipitation and the elevation have slightly negative impact, - 0.1 and – 1% respectively. The precipitations are quite abundant throughout the study area, surely not representing a limitation for agricultural practices – the minimum is 1281 and the maximum 2873mm, with a north-south gradient; rather, very often in alpine areas the precipitation increases with increasing elevation (Daly et al. 1997). This is for sure an over simplification but it might explain the relationship precipitation-agriculture. The increasing of one unit of slope results in a – 3% in the odds for the occurrence of agricultural areas. The soil does not affect or affects negatively agriculture. The rendzina soils are often very primitive soils lying directly on the bedrock matrix, often calcic (FAO 1976), showing a decrease in the odds of the agriculture by a 33 and 57%. The presence of the Gleyc Podzol impacts the occurrence of this class by – 47%. The temperature does not seem to be a constraint.

Forest. The share of enterprises in the first sector and the slope inclination seem to have a slightly positive influence (respectively + 2 and + 6%) on the odds of the occurrence of the forest. Forest is more likely to occur on steeper slopes, while the more flat areas are preferably kept for settlements. The geology has a stronger impact (lime stone + 53%). The elevation has almost no relevant effect on the odds of forest occurrence (- 0.2%). Employees in the first sector, distance from the city, aspect, detrital and alluvial geology have no impacts.

Table 12 Results of the Binary Logistic Regression and of the ROC analysis – (blank) excluded manually, (*) dropped out from the model. All the variables are significant at p < 0.01.

		0_URBAN		1_INDUSTRIAL		2_AGRICULTURE		3_FOREST		4_GRASSLAND		5_BARE LAND		6_WATER	
Driver	***Code***	***β***	***Exp(β)***	***β***	***Exp(β)***	***β***	***Exp(β)***	***Β***	***Exp(β)***	***β***	***Exp(β)***	***β***	***Exp(β)***	***β***	***Exp(β)***
EMPLOYEES_i	***0***	-0,313	*0,73*			0,085	*1,09*	*	*	*	*				
EMPLOYEES_ii	***1***	-0,016	*0,98*	0,0298	*1,03*										
EMPLOYEES_iii	***2***	-0,019	*0,98*												
ENTERPRISES_i	***3***	*	*			*		0,014	*1,02*	0,043	*1,04*				
ENTERPRISES_ii	***4***	*	*	0,037	*1,04*										
ENTERPRISES_iii	***5***	-0,075	*0,93*												
POP DENSITY	***6***	0,001	*1,001*	-0,0026	*0,997*							0,002	*1,00*	*	*
PRIVATE HOUSING	***7***	*	*												
DISTANCE STATION	***8***	*	*	0,0001	*1,00*							*	*		
DISTANCE CITY	***9***	*	*	-0,0001	*1,00*			*	*			*	*	*	*
PRECIPITATION	***10***					-0,001	*0,99*			*	*	0,001	*1,001*	-0,007	*0,99*
DISTANCE SCHOOL	***11***	*	*												
DISTANCE STREET	***12***	*	*	-0,0007	*0,99*	*	*					*	*	*	*
ASPECT	***13***	*	*			*	*	*	*	*	*	*	*	*	*
ELEVATION	***14***	-0,007	*0,99*	-0,0073	*0,99*	-0,008	*0,99*	-0,002	*0,998*	0,002	*1,002*	0,003	*1,003*	*	*
Geo_CALC	***15***							0,428	*1,53*	*	*	*	*	6,656	*777,54*
Geo_DETRIT	***16***							*	*	-0,467	*0,63*	-2,379	*0,09*	5,801	*330,65*
Geo_ALLUV	***17***							*	*	*	*	-3,858	*0,02*	8,801	*6642,6*
SLOPE	***18***	-0,034	*0,97*	*	*	-0,035	*0,97*	0,061	*1,06*	-0,036	*0,97*	0,035	*1,04*	-0,116	*0,89*
Soil_CALC FLUVI	***19***					*	*			0,462	*4,59*	-2,176	*0,11*	*	*
Soil_CALC LITHO	***20***					*	*			*	*	-2,366	*0,09*	*	*
Soil_CAMB RENDZ	***21***					-0,401	*0,67*			0,678	*1,97*	-6,001	*0,002*	*	*
Soil_GLEY PODZ	***22***					-0,641	*0,53*			*	*	*	*	1,534	*4,64*
Soil_ORTH RENDZ	***23***					-0,747	*0,47*			*	*	*	*	*	*
Temp [-2 – 0]	***24***					*	*			*	*	*	*		
Temp [0 – 2]	***25***					*	*			1,199	*3,32*	1,084	*2,96*		
Temp [2 – 4]	***26***					*	*			1,798	*6,04*	*	*		
Temp [4 – 6]	***27***					*	*			0,947	*2,58*	-0,855	*0,43*		
Temp [6 – 8]	***28***					4,70				0,883	*2,42*	-1,019	*0,36*		
Temp [8 – 10]	***29***					4,371				0,620	*1,86*	*	*		
	Constant	**8,4**		**1,24**		**-0,85**		**0,04**		**-2,92**		**-6,83**		**-7,05**	
	ROC	**0,95**		**0,95**		**0,89**		**0,72**		**0,76**		**0,93**		**0,97**	

Grassland. Again the share of enterprises in the first sector have a positive influence on this land use (+ 4%). The elevation has very low positive influence (+ 0.2%). The soil has very strong positive influence, the calcaric fluvisoil and the cambic rendzina impact the occurrence of the grassland respectively by a + 359 % and + 97%. The temperature has also strong positive effects – except for the coldest category, which is relegated in the southwestern corner of the area at high elevation. From the lower to the higher temperature: + 232, + 504, + 158, + 142 and + 86%. The detrital geology and the slope inclination have negative impact on the odds of the grassland, respectively – 37 and – 3%.

Bare land. According to the model, the population density has slightly positive influence on the occurrence of the bare land (+ 0.2%), as well as the yearly precipitation (+ 0.1%) and the elevation (+ 0.3%). The presence of detrital and alluvial geologic formations decreases the probability of this class respectively by the 9 and 2 %; in fact these two formation are linked with fluvial and/or past glacial processes which occur in the valley bottom, while the bare rocky land is most likely occurring higher up in elevation. With increasing slope by one degree unit the odds for bare land increase of a 4%. The soils follow more or less the negative trend of the geology: calcaric fluvisoil (- 11%), calcaric lithosoil (- 9%), cambic rendzina (- 0.2%); the other geologic formations have no impact. The temperature category from 0 to + 2° C has a very high impact, + 196 %, while the categories 4-6° C and 6-8° C have a negative impact, respectively by - 57 and - 64 %. Bare land are often linked with high altitude environment where the temperature does not allow to the plant communities to install a permanent bio-cenosis.

Water. An increase in the precipitation seems to have a negative impact, though very low, on the water occurrence (- 1 %). As it was already said above, the precipitation are well above 1 000 mm in the area. Upon the increasing by one degree of the slope inclination the odds for this class decrease by 11 %; in fact, according to the CORINE classification, the water bodies are small lakes or basins that lay in the flat valley bottom. The gleyc podzol seems to have a strong positive impact on the water occurrence (+ 364 %). Finally, the results of the logit model show incredibly high values in all the three geologic formations, which is probably due to the small sample size of the water class (Bull et al. 2002).

The results of the logistic regression were generally in line with other case studies from all over the world (Zheng et al. 2012; Cammerer et al. 2013). The performances of the logistic regressions were tested and evaluated through the ROC analysis method. In order to assess the goodness of fit of the statistical model, this test was performed, providing a measure of how good – up to which extent the model is able to represent the reality – is our statistical model. The relative operating characteristic method (ROC) is able to measure the quality of the predictors, namely the relation of the explanatory factors and the land use. The ROC characteristic is a measure for the goodness of fit of a logistic regression model (Pontius & Schneider, 2001). A completely random model gives a ROC value of 0.5 while a perfect fit results in a ROC value of 1.0. The suitability model was the same in all scenarios (e.g. Price et al. 2015). The results showed in the last line in Tab. 12, are very satisfying. They show in fact values above 0.89 in the urban, industrial, agriculture, bare land and water classes. Only the forest and the grassland showed slightly lower values (respectively, 0.72 and 0.76). Values of 0.7 represent in the literature a reasonable fit, while values of 0.9 are considered outstanding fit (Hosmer & Lemeshow 2000).

5.2 Calibration and validation

In order to calibrate all the input parameters of the model, the maps of CORINE land use in 2006 and 2012 were used. The calibration runs were performed running the model from 2006 to 2012. The scenario that was chosen was simply a regression calculation, using the surfaces in 2006 and 2012, deriving the values in the missing years. The simulated outputs in 2012 were then confronted with the 2012 “reality map” provided by CORINE. The calibration was undertaken editing the elasticity values in order to obtain an outcome as much as possible close to the reality. The calibration runs were performed testing all the restriction configurations – no restrictions, light restrictions, medium and heavy restrictions.

The calibration and the visual/statistic validations were undertaken simultaneously. First of all, the outputs undergo a visual comparison phase where the simulated 2012 maps were compared to the 2012 reference map by CORINE (Fig. 21). After this glance, which aimed at detecting macro-errors, the output passed through the statistical validation using the ArcGIS tool *Tabulate Area* ArcGIS tool (*Spatial Analyst*). This tool put in a tabular comparison the simulated output and the real/reference map (Pontius et al. 2008; Bowman et al. 2012). A total number of more than 85 calibration runs were performed; at first the model was calibrated with the no restrictions configuration and then with the three restriction configurations. To adjust the outcomes the elasticities – for a smaller extent also the conversion matrix – were edited.

The outcome of the *Tabulate* Area is a matrix table of reference pixels/simulated pixels (Tab. 13, 14, 15, 16). With the statistical validation, the accuracies for each land use class could be calculated. There are three types of accuracies to be calculated: the Producer, the User and the Overall Accuracy. The Producer Accuracy is calculated through the rate between the correctly allocated pixels of the simulation output with the pixels in the “reality” map in 2012 (*Sum Corine*). The User Accuracy is the rate between the correctly allocated pixel of the simulated output and the sum of the overall allocated pixels in the considered land use class (*Sum model*). The Overall Accuracy is calculated through the rate between the overall correctly allocated pixels among all the classes (Sum *Correct*) and the total number of pixels belonging the study area (33 951). To give an example, let us consider the urban class in the *Run_77*:

*Producer Accuracy (urban77) = [Correct] / [Sum**] = 3689 / 3829*

User Accuracy (urban77) = [Correct] / [Sum] = 3689 / 3873*

Overall Accuracy (urban77) = [Sum Correct] / [Total Area] = 31457 / 33951

Table 13. Tabulate Area of the calibration run n. 77. The matrix displays the pixel allocation: in bold (diagonal) the correctly allocated pixels, the other values are the pixel that were spread out in other classes. At the bottom of the table the Accuracies: Producer accuracy (Prod Acc), User Accuracy (User Acc) and Overall Accuracy (Over Acc).

Run77		**Corine classification (2012)**							
		URBAN	**INDUSTRIAL**	**AGRICULTURE**	**FOREST**	**GRASSLAND**	**BARE LAND**	**WATER**	***[Sum Simulated]***
Simulated	**URBAN**	**3689**	49	74	27	34	0	0	*[3873]*
	INDUSTRIAL	3	**194**	61	2	0	0	0	*[260]*
	AGRICULTURE	61	7	**2152**	26	241	0	0	*[2487]*
	FOREST	56	21	89	**17469**	642	84	2	*[18363]*
	GRASSLAND	20	1	78	760	**5848**	106	1	*[6814]*
	BARE LAND	0	0	0	17	29	**1819**	0	*[1865]*
	WATER	0	0	0	2	0	0	**286**	*[288]*
	[Sum CORINE]	*[3829]*	*[272]*	*[2454]*	*[18303]*	*[6794]*	*[2009]*	*[289]*	***[31457]***
	Prod Acc	0,963	0,713	0,877	0,954	0,861	0,905	0,990	
	User Acc	0,952	0,746	0,865	0,951	0,858	0,975	0,993	
						Over Acc	***0,927***	***93%***	

Table 14. Tabulate Area of the calibration run n. 83B. The matrix displays the pixel allocation: in bold (diagonal) the correctly allocated pixels, the other values are the pixel that were spread out in other classes. At the bottom of the table the Accuracies: Producer accuracy (Prod Acc), User Accuracy (User Acc) and Overall Accuracy (Over Acc).

Run83B		**Corine classification (2012)**							
		URBAN	**INDUSTRIAL**	**AGRICULTURE**	**FOREST**	**GRASSLAND**	**BARE LAND**	**WATER**	***[Sum Simulated]***
Simulated	**URBAN**	**3689**	49	73	27	19	0	0	*[3857]*
	INDUSTRIAL	3	**194**	52	2	1	0	0	*[252]*
	AGRICULTURE	61	7	**2175**	27	206	0	0	*[2476]*
	FOREST	56	21	76	**17400**	688	86	2	*[18329]*
	GRASSLAND	20	1	78	826	**5851**	116	1	*[6893]*
	BARE LAND	0	0	0	19	29	**1807**	0	*[1855]*
	WATER	0	0	0	2	0	0	**286**	*[288]*
	[Sum CORINE]	*[3829]*	*[272]*	*[2454]*	*[18303]*	*[6794]*	*[2009]*	*[289]*	***[31402]***
	Prod acc	0,96	0,71	0,89	0,95	0,86	0,90	0,99	
	User acc	0,96	0,77	0,88	0,95	0,85	0,97	0,99	
						Over Acc	***0,925***	***93%***	

Table 15. Tabulate Area of the calibration run n. 84A. The matrix displays the pixel allocation: in bold (diagonal) the correctly allocated pixels, the other values are the pixel that were spread out in other classes. At the bottom of the table the Accuracies: Producer accuracy (Prod Acc), User Accuracy (User Acc) and Overall Accuracy (Over Acc).

Run84A		**Corine classification (2012)**							
		URBAN	**INDUSTRIAL**	**AGRICULTURE**	**FOREST**	**GRASSLAND**	**BARE LAND**	**WATER**	***[Sum Simulated]***
Simulated	**URBAN**	**3689**	49	75	27	26	0	0	*[3866]*
	INDUSTRIAL	3	**194**	50	2	2	0	0	*[251]*
	AGRICULTURE	62	7	**2175**	27	233	0	0	*[2504]*
	FOREST	56	21	76	**17402**	683	85	2	*[18325]*
	GRASSLAND	19	1	78	824	**5821**	116	1	*[6860]*
	BARE LAND	0	0	0	19	29	**1808**	0	*[1856]*
	WATER	0	0	0	2	0	0	**286**	*[288]*
	[Sum CORINE]	*[3829]*	*[272]*	*[2454]*	*[18303]*	*[6794]*	*[2009]*	*[289]*	***[31375]***
	Prod Acc	0,96	0,71	0,89	0,95	0,86	0,90	0,99	
	User Acc	0,95	0,77	0,87	0,95	0,85	0,97	0,99	
						Over Acc	***0,924***	***92%***	

Table 16. Tabulate Area of the calibration run n. 82C. The matrix displays the pixel allocation: in bold (diagonal) the correctly allocated pixels, the other values are the pixel that were spread out in other classes. At the bottom of the table the Accuracies: Producer accuracy (Prod Acc), User Accuracy (User Acc) and Overall Accuracy (Over Acc).

Run82C		**Corine classification (2012)**							
		URBAN	**INDUSTRIAL**	**AGRICULTURE**	**FOREST**	**GRASSLAND**	**BARE LAND**	**WATER**	***[Sum Simulated]***
Simulated	**URBAN**	**3689**	49	95	27	20	0	0	*[3880]*
	INDUSTRIAL	3	**194**	22	2	0	0	0	*[221]*
	AGRICULTURE	62	7	**2141**	24	241	0	0	*[2475]*
	FOREST	56	21	118	**17449**	645	64	2	*[18355]*
	GRASSLAND	19	1	78	780	**5858**	104	1	*[6841]*
	BARE LAND	0	0	0	19	30	**1841**	0	*[1890]*
	WATER	0	0	0	2	0	0	**286**	*[288]*
	[Sum CORINE]	*[3829]*	*[272]*	*[2454]*	*[18303]*	*[6794]*	*[2009]*	*[289]*	***[31402]***
	Prod acc	0,96	0,71	0,87	0,95	0,86	0,92	0,99	
	User acc	0,95	0,88	0,87	0,95	0,86	0,97	0,99	
						Over Acc	***0,927***	***93%***	

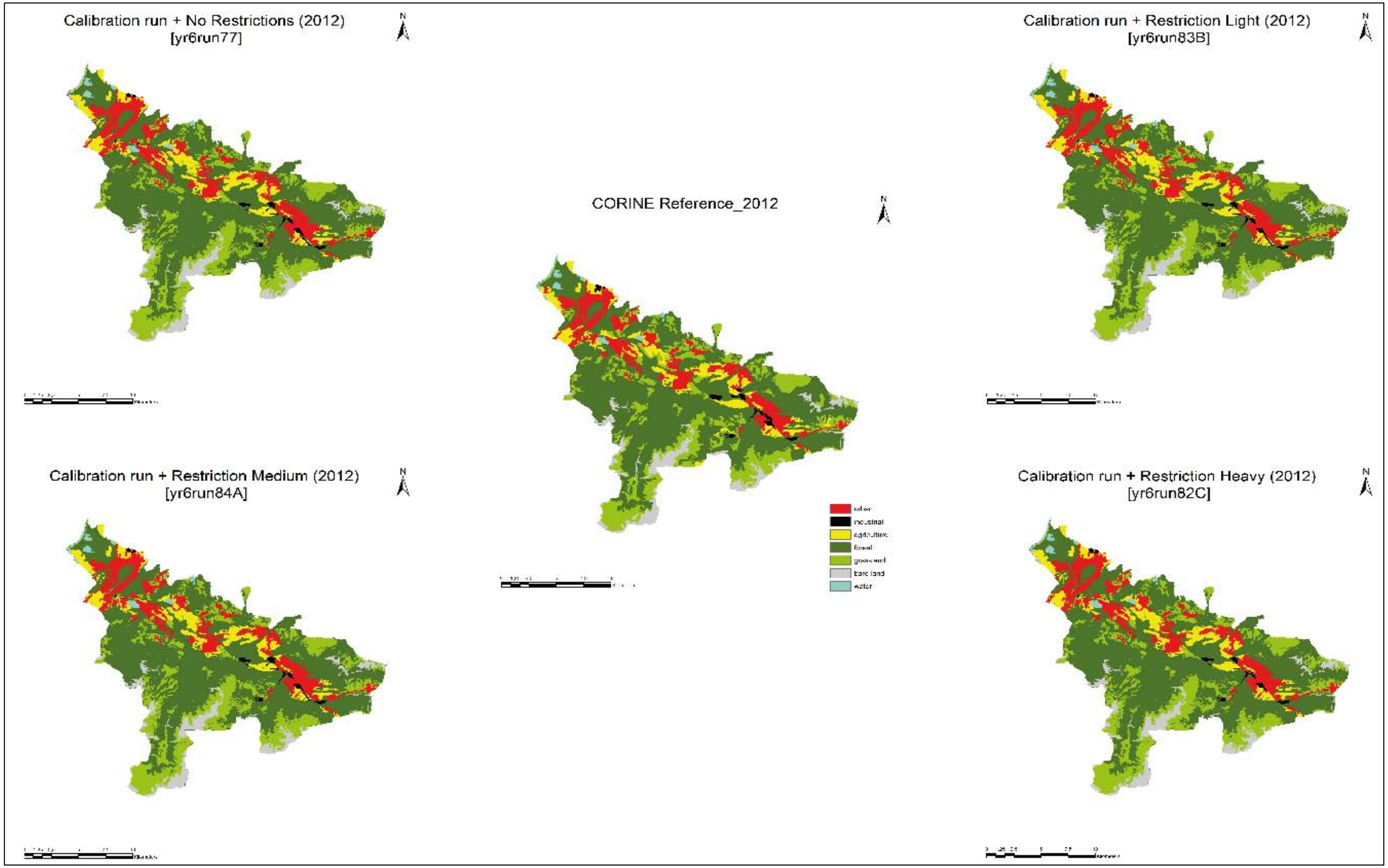

Figure 21. Comparison between the reference map (CORINE2012) and the simulated maps with the different restriction configurations. These maps are the results of the calibration procedure.

As it was already mentioned, these results were obtained through the calibration of the elasticities written in the *main.1* file, through the GUI of the Dyna-CLUE. Also the matrix had to be adjusted in order to reach the actual outcomes. The definitive values of the matrix are displayed in the Tab. 17.

Table 17. Conversion matrix and Elasticities, as they were used for the further simulations. Zero means the conversion is not allowed, one the conversion is allowed. The values of the elasticity express how likely the considered class might change into another one; it ranges from 0 (easy conversion) to 1 (irreversible conversion).

		landuse (t+1)						
		URB	**COMM**	**AGR**	**FOR**	**GRASS**	**BARE**	**WAT**
landuse (t)	**URB**	1	1	0	0	0	0	0
	COMM	0	1	0	0	0	0	0
	AGR	1	1	1	1	1	0	0
	FOR	0	0	0	1	1	0	0
	GRASS	0	0	1	1	1	0	0
	BARE	0	0	0	1	1	1	0
	WAT	0	0	0	1	1	0	1
		0.9	***1.0***	***0.6***	***0.7***	***0.3***	***0.4***	***0.8***

Also the variable called *Seed for iteration* was slightly changed in order to allow the model to find smoothly the solution when a part of the study area was under restriction. The variable is composed by three numbers; only the second number was here edited, while the others were left to default values. This number expresses the convergence criteria: average deviation between demanded changes and actually allocated changes (default for % : 0.35; for the absolute iteration mode at least the cell area divided by the number of land use types) (Verburg & Veldkamp 2002). The seed for iteration used in the run 77 with no restrictions was 0.03. The seed for iteration used with the three restriction configurations (run 83B, 84A and 82C) was 0.025000.

The results obtained were quite satisfying, since the producer accuracies have values always above 0.86 and the user accuracies above 0.85 in all the land use classes except for the industrial (from 0.71 to 0.88). The accuracies of the "industrial" class in the simulated maps shows values well below the other classes; this is due to the lower relative surface of commercial units compared to other land use classes. The Dyna-CLUE is a probabilistic model thus, with one class with relative lower sample size among classes with bigger surfaces, it is harder to allocate the pixels in the right place – with big sample size the pixel that has to be allocated is more likely to pick the right locality. After obtaining these maps, it was decided to check and compare more in detail the two maps from CORINE: the map from 2006 and the reference 2012 map. The visual analysis was aimed at finding classification discrepancies which may have caused the low accuracy of the industrial class, and it will be debated in the following paragraph.

5.2.1 Visual comparison: CORINE 2006, 2012/Orthophoto 2006

This analysis pointed out important and significant classification differences within the different CORINE maps throughout the years. This problem was already noticed in the preliminary phase of the study, when it popped out to be clear that the CORINE land use map in 1990 was substantially different from the 2012 map. This was clearly not due to land use changes happen in the two decades, it was though caused by a substantial improvement of the technologies and methods of the remote sensing and classification implemented by the CORINE project. This issue was considered to be not present between the 2006 and 2012 maps. Although it was not as big as in the 1990-2012 comparison, it surely affected the simulation outcomes and their accuracy.

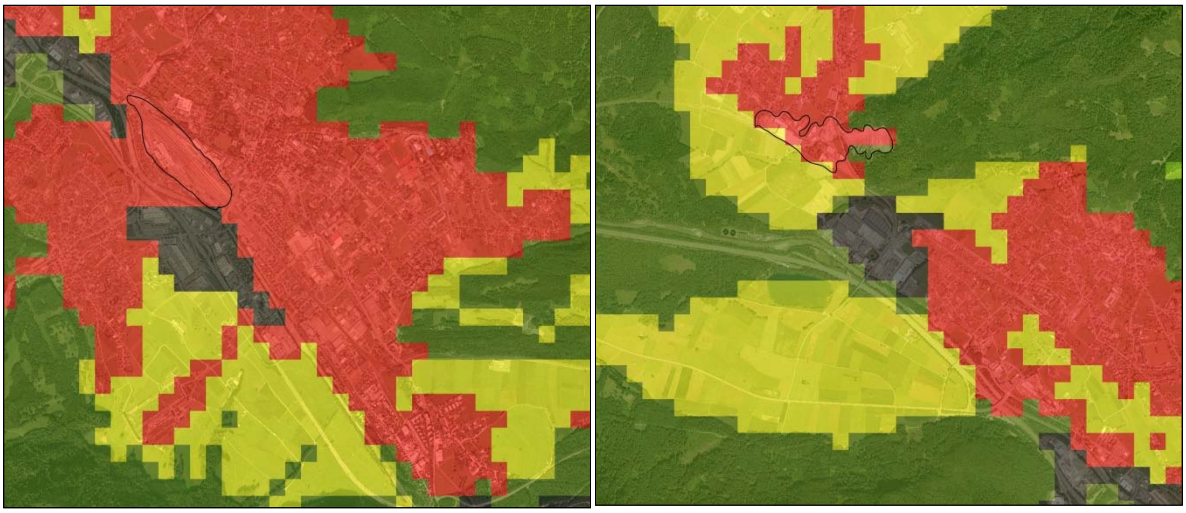

Figure 22. Overlapping between the orthophoto in 2006 (source: Land Vorarlberg Atlas) and the CORINE 2006 land use map. These two snapshots want to underline the classification issues of the land use database used in the simulations. The two polygons are areas which in 2006 were classified as urban, while as the 2006 orthophoto shows they are industrial zones. The problem is that in CORINE 2012 they were classified as industrial. The right image shows the Railway station in Bludenz (ca. 16 ha), on the left and industrial zone in the municipality of Ludesch (ca. 15 ha).

The Fig. 22 shows the classification problem that affected the simulation outcomes. The two areas amount at ca. 30 ha, and considering that the "industrial" amounts at 200 and 272 ha according to the CORINE, respectively in 2006 and 2012, it is already comprehensible the weight that this have on the outcome quality and accuracy. The model in fact allocated the right amount as "industrial" but it did not pick up the right location where to allocate the 72 ha of difference between 2006 and 2012. According to the model settings and according also to the logic, a new industrial area is more likely to pop up on some agricultural area or grass land, rather than within the urban space. And this is exactly what the model did: the area difference was allocated in the "agricultural" in both the above mentioned cases (Fig. 23).

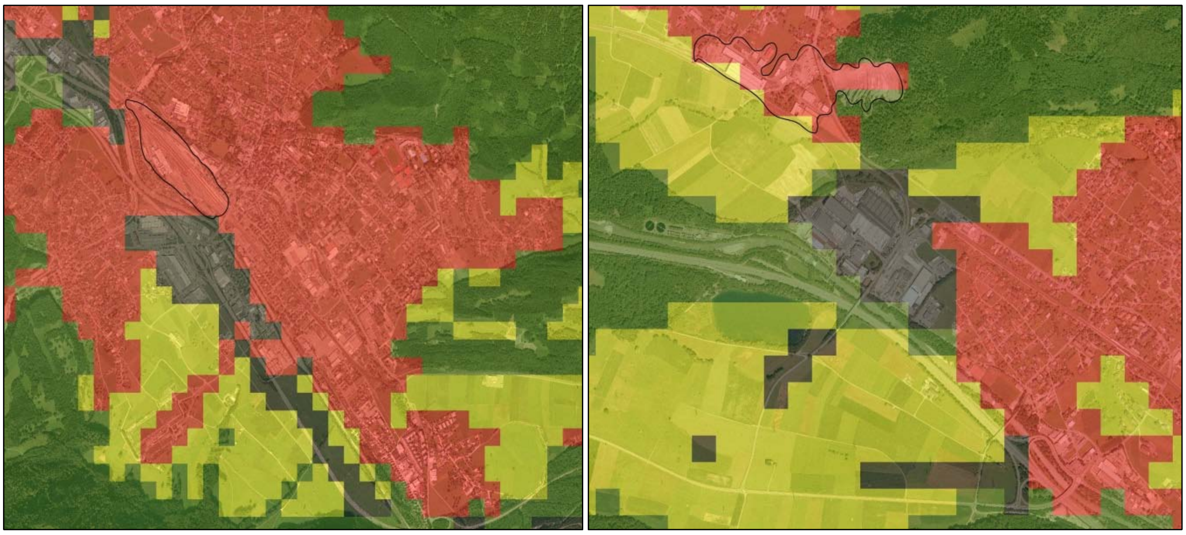

Figure 23. Overlapping between the orthophoto in 2006 (source: Land Vorarlberg Atlas) and the simulated 2012 land use map (run 77). The model allocated – according to the land demand (quantity) and the driving factors (locality) – the "industrial" in both cases eating the adjacent agricultural areas, rather than making the conversion of "urban" into "industrial", which is even not allowed by the matrix.

5.3 Scenarios

The demand is calculated at aggregate level as part of a specific scenario. These files are needed to give the model the magnitude of the land use change in the simulated time period. The preparation of these files is made outside the CLUE, based on a wide range of methods. we chose the already available spatial planning scenarios by the ÖROK, Austrian Conference on Spatial Planning (ÖROK, 2008). As already mentioned in the chapter "Methodology and data", the national scenarios have to be adapted to the Ill-Walgau spatial pattern. Due to the peculiarities of this area a downscaling process were implemented in order to quantify the relative variation of each land use class within the time range (Fig. 24 a, b, c, d).

The *Overall Growth* scenario (Tab. 18) is defined as a population growth scenario, thus it results as the most urbanization-oriented among the four. The trend is led by a strong urbanization in the period 2006-2030 (+ 20 %) and building of new industrial areas (+20.1 %). These classes develop affecting directly the agriculture and the grassland, which see a decrease in their surface of 3.48 and 11.73 % respectively. The alpine agriculture – either intensive in the valley bottom or extensive in the higher altitudes pastures and meadows – abandonment leads to the concentration of population and buildings in the valley bottom. The market is the main driver of the dynamics in this scenario. In the *Overall Competition* (Tab. 18) the urbanization push is less strong than in the first scenario, thus the pressure on the land is less extreme, but still high in the growth zones (e.g. urban and industrial areas). Other regions are confronted with migration and population shrinking. Urban and industrial grow by a + 13.2 %, while agriculture and grassland experience lower surface shrinkage (- 1.29 and – 10 % respectively).

Table 18. Summary of the four spatial scenarios: total hectares and percentage in 2006; variation in hectares and percentage from 2006 to 2030, within the four scenarios; total hectares in the four scenarios 2030 in hectares and percentage.

	CORINE		OVERALL GROWTH [.in2]				OVERALL COMPETITION [.in3]				OVERALL SECURITY [.in2]				OVERALL RISK [.in3]			
	tot_06		Variation 06-30		tot_30		Variation 06-30		tot_30		Variation 06-30		tot_30		Variation 06-30		tot_30	
	ha	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*
urban	3801	*11,20*	760	*20*	4561	*13,43*	*501,73*	13	4303	*12,67*	*300,28*	8	4101	*12,08*	229	*6,03*	4030,33	*11,87*
industrial	200	*0,59*	40	*20,1**	240	*0,71*	*26,4*	13	226	*0,67*	*15,8*	8	216	*0,64*	12	*6,03*	212,07	*0,62*
agriculture	2392	*7,05*	-83	*-3,48*	2309	*6,80*	*-30,857*	-1	2361	*6,95*	*-23,92*	-1	2368	*6,97*	-22	*-0,9*	2370,47	*6,98*
forest	18483	*54,44*	83	*0,45*	18566	*54,68*	*184,83*	1	18668	*54,99*	*739,32*	4	19222	*56,62*	739	*4*	19222,3	*56,62*
grassland	6822	*20,09*	-800	*-11,73*	6022	*17,74*	*-682,2*	-10	6140	*18,08*	*-1031,5*	-15	5791	*17,06*	-959	*-14,06*	5862,83	*17,27*
bare land	*1965*	*5,79*	0	*0*	1965	*5,79*	*0*	0	1965	*5,79*	0	*0*	1965	*5,79*	0	0	1965	*5,79*
water	288	*0,85*	0	*0*	288	*0,85*	*0*	0	288	*0,85*	0	*0*	288	*0,85*	0	0	288	*0,85*

*High industrialised hence + 0.1 % for industrial with respect to urban.

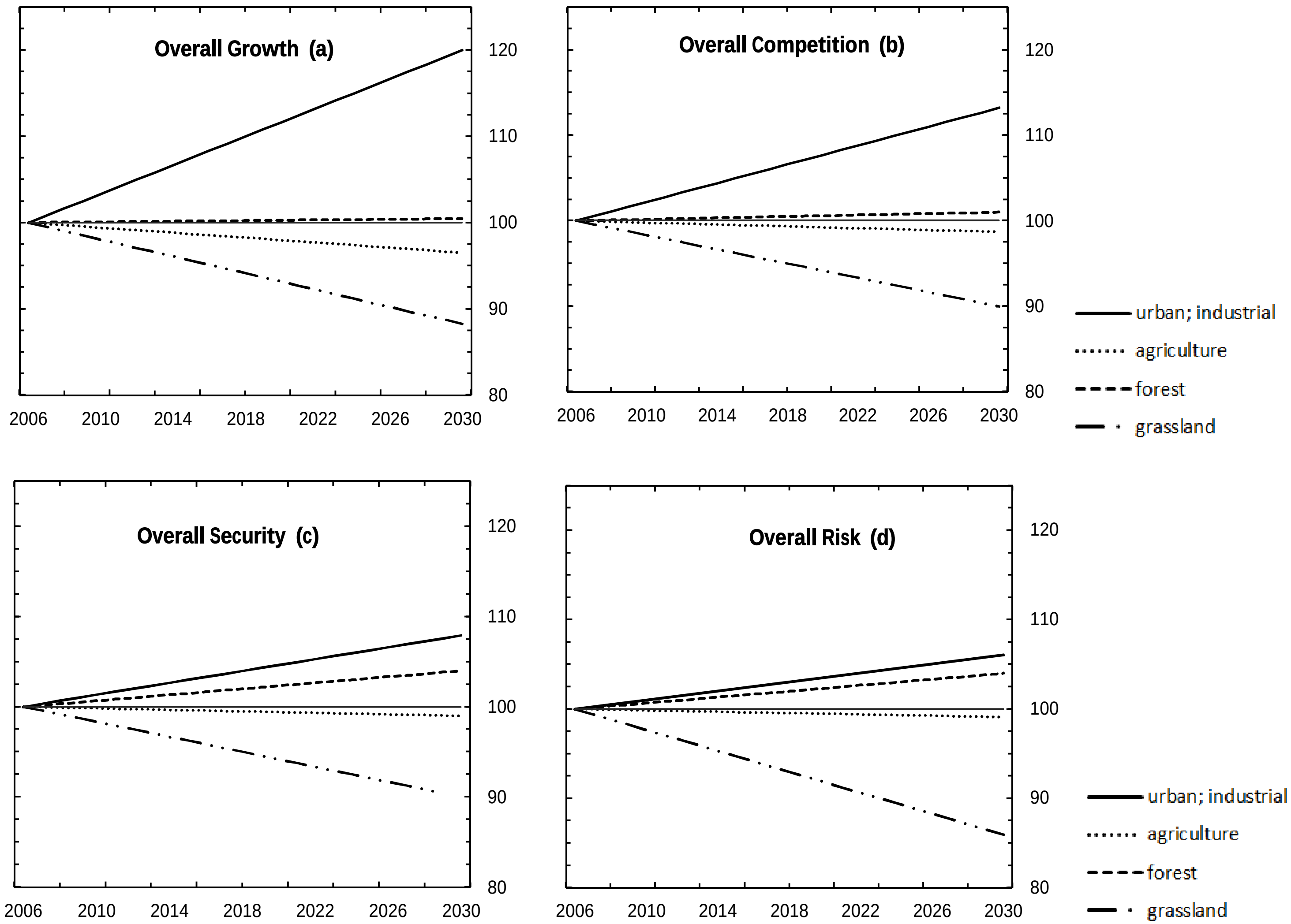

Figure 24. Displays of the scenario trends: on the x-axis the years, on the y-axis the variation in percentage: (a) is the Overall Growth, (b) is the Overall Competition, (c) is the Overall Security, (d) is the Overall Risk scenario.

Overall Security scenario (Tab. 18) is characterized by a moderate growth of most of the driving forces. In those regions suitable for forestry and farming the pressure will increase due to higher demand from renewable energy (e.g. biomass). Due to higher prices of energy and fuel, thus high mobility costs, the urban agglomeration and centralization are favored. The growth rates of urban and industrial are half of previous scenario ones (- 7.9 %). Agriculture stays pretty much stable (- 1 %) while the forested area increase by a 4 % occupying mainly part of the grassland (- 15.1 %). *Overall Risk* (Tab. 18) shows similar driving forces dynamics as the previous scenario, but no mechanism against sudden energy scarcity are developed. The spatial development is determined by more densely built-up areas and more intense exploitation of natural resources for energy purposes. Urban and industrial grow by a 6 %, agriculture decrease slightly its surface (- 0.9 %), while forest grows by 4 % and grassland decreases the surface by a 14 %.

The four scenarios quantify the aggregate surface for each land use class at the end of the simulation period (2030). In order to build the demand file which can be handled by the model, the relative surfaces of the classes has to be calculated during every year of the simulation process. The δ% obtained was therefore multiplied with the total hectares in 2006; the variation in hectares was then added to the surface in 2006 to obtain the surface in ha in 2030, for each scenario and land use class. Since the demand file has to express on a yearly basis the surfaces of each class, the surfaces in the intermediate years were derived with a simple regression. The scenario files, which are composed by seven columns (land use classes) and 25 rows (2006-2030), were converted into text format and named *demand.in2*, *demand.in3*, *demand.in4*, *demand.in5*.

5.4 Dynamics of the exposure to natural-hazards

Overlapping the outcomes of the simulation with the actual hazard zonation (for more details please see *"4.5.1 Restriction policies and hazard zoning"*), it was possible to perform the exposure analysis in 2030. Having four spatial scenarios and four restriction configuration to test, the simulated maps in 2030 were sixteen. The analysis was performed counting the pixels which lay under the mask of the different hazard zones. The cross-check procedure aims at assessing the amount of land falling under the hazard zones, defined by the WLV and the BMLFUW. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask. A number of four hazard zones were defined (Fig. 25): the red zones – where the actual building ban is implemented, the yellow zones – settlements are allowed with specific requirements, the HQ30 (with the probability for the designed event is one every thirty years) and the HQ31-100 (subtraction of the HQ30 form the HQ100, which are the zone where the event is expected one in one-hundred years) (WLV 2013; Fuchs et al. 2015). The total amount of the surface under hazard was 1402 ha (red and yellow zones, HQ100).

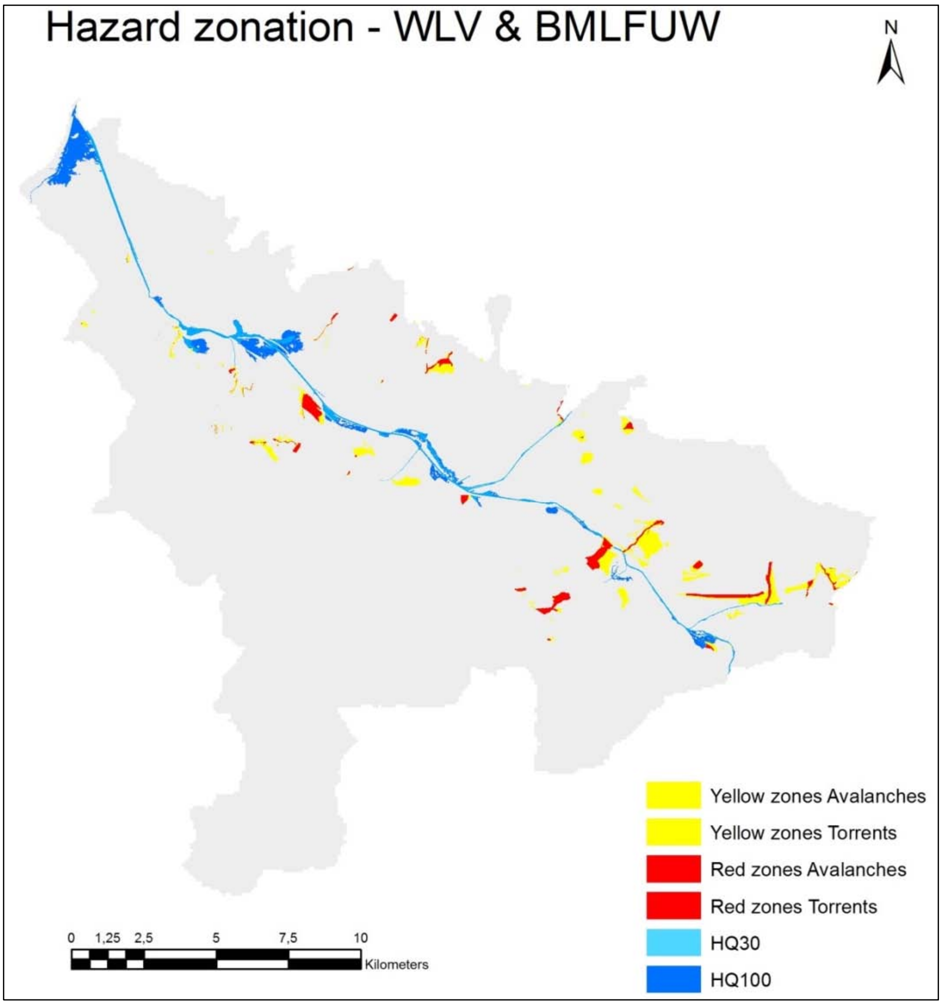

Figure 25. Hazard zonation in the Ill-Walgau. For more information please see 4.5.1 in the Methodology and Data chapter.

5.4.1 Exposure in 2006

The hazard zonation identifies a total of 1402 ha exposed to natural hazards. Within this total surface the zones are distributed as follows: 675 ha are the domain of the BMLFUW – 288 ha in the HQ30 and 387 ha in the HQ31-100; 727 ha are under the jurisdiction of the WLV – 234 ha are in the Red zones and 493 ha in the yellow. The exposure to natural hazards in 2006 is distributed among the classes as Tab. 19 shows. The biggest part of exposed land in the study area is forest (41.4 %): 123 ha of forest in 2006 are in the red zones, 74 ha in the yellow, 178 ha in the HQ30 and 206 ha in the HQ31-100. The high share of hazarded forested land it is explainable with the fact that forested land has not only a big share in the overall area of the study location, but also because forests are located very often in remote and steep zones or along the river beds. Furthermore, as the majority of the hazard threats in alpine environment are represented by gravitational mass movements, the forest which provide a protection function (*Schutzwald*[2]) are located in steep slopes and at high elevation where hazard take place, propagate and/or deposit (Brang et al. 2008). Besides that in the Ill-Walgau the forested areas under hazard are also located at the valley bottom along the river Ill – for instance, a considerable area of forest threatened by flood is located downstream form the city of Feldkirch. The second class in size to be under hazard is the urban (28.7 % of the total hazarded area): the biggest part of the urban threatened by natural hazards is located in the yellow zones (262 ha), while in the red zones there are 34 ha; the HQ30 and HQ31-100 have respectively 50 and 56 ha of urban. While the exposed urban in the red zones is relatively low, in the yellow zones and in the HQ is considerably higher. In these zones no building ban is legally implemented, and with future climatic uncertainties the hazard zonation might experience changes due to the changing conditions (i.e. Allamano et al. 2009; Bouwer et al. 2010; Mazzorana et al. 2012; Staffler et al. 2008).

[2] *Schutzwald* (Protective forest). The definition of protective forest comes from the Forest Act (1976), when the function that certain forests provide was formalized in the law. Through their presence these forests protect settlements and transport network (e.g. roads, railroads, etc.). In Austria ca. 20 % of the total forested area is protective forest. The protective function is provide against the gravitational natural hazards, like snow avalanches, debris flow, rock fall, floods, etc. In order to provide their function they must undergo a proper management regime, being their value far above the commercial values like in normal forests. In fact, without these forests many part in Austria and in the other alpine countries, would be not settable. There are three type of protective forest as recognized by the Austrian law. *Bannwälder* or banned forests, are a special type of protective forests; defined also as welfare forests, as by their presence they directly influence the hazard propagation. *Objektschutzwälder* or object-protective forest, are those forests which protect people, settlements, cultivations from negative impacts of natural hazards. *Standortschutzälder* or site-protective forest, are those forests which are located in fragile location prone to environmental degradation from the wind, water or erosion (Republik Österreich 1975).

Table 19. Distribution of the land threatened by natural hazards in hectares and in percentage. The latter is calculated as the rate between the hazarded area of the considered land use class and the total hazarded area considering red and yellow zones, and HQ100 (1402 ha).

	ha	***%***
urban	402	*28,67*
industrial	28	*2,00*
agriculture	69	*4,92*
forest	581	*41,44*
grassland	231	*16,48*
bare land		
water	91	*6,49*
sum	1402	*100*

The 16.5 % of the area under hazard is grassland: 54 ha are in the red zones, 130 ha in the yellow zones, 21 ha and 26 ha in the HQ30 and HQ31-100 respectively. The grassland, in a similar way with forests, are also often situated in steep areas. Water and agriculture account for respectively 6.5 and 4.9 % of the hazardous area. Water is situated by definition along the river, thus the water area under hazard is mainly in HQ zones – 14 in the HQ30 and 76 ha in the HQ31-100. Agriculture is more spread within the four zones: 23, 18 and 23 ha are respectively in the yellow zones, HQ30 and HQ31-100; 8 ha are in the red zones. Only the 2 % of the hazarded land is industrial. This is due to the relatively low surface that this land use class has with respect to the others – in 2006 only 0.6 % of the total area is industrial. Besides that, the distribution of this class is interesting, in fact 15 ha are situated in the red zones, 3 ha in the yellow zones and in the HQ31-100, and 7 ha in the HQ30. This means that the 7.5 % of the industrial is located inside red zones, which are for definition the most endangered.

5.4.2 Exposure in 2030

No Restrictions

The total abolishment of the planning regulation was simulated; here there is no building policy aimed at controlling the urban development in exposed areas. The cross-check procedure aims at assessing the amount of land falling under the hazard zones. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask (Tab. 20).

Table 20. Summary tab for the No Restrictions configuration. The four spatial scenarios and the surfaces under hazard of each single land use class are displayed divided in the four zones – red and yellow zones, HQ30 and HQ31-100. The second last column shows the sum of the land threatened by hazards for each class. The delta_% column is the relative change of exposed land in comparison with 2006.

		No Restrictions					
	[ha]	**red**	**yellow**	**HQ30**	**HQ31-100**	**tot**	**delta_%**
GRO	***urban***	34	262	70	65	431	*7,21*
	industrial	16	3	10	3	32	*14,29*
	agriculture	21	84	13	35	153	*121,74*
	forest	143	97	181	208	629	*8,26*
	grassland	20	46			66	*-71,43*
	bare land						
	water		1	14	76	91	*0,00*
COMP	***urban***	34	262	70	61	427	*6,22*
	industrial	15	3	9	3	30	*7,14*
	agriculture	19	64	13	39	135	*95,65*
	forest	144	95	182	208	629	*8,26*
	grassland	22	68			90	*-61,04*
	bare land						
	water		1	14	76	91	*0,00*
SEC	***urban***	34	262	62	58	416	*3,48*
	industrial	15	3	9	3	30	*7,14*
	agriculture	11	37	19	42	109	*57,97*
	forest	152	118	184	208	662	*13,94*
	grassland	22	72			94	*-59,31*
	bare land						
	water		1	14	76	91	*0,00*
RISK	***urban***	34	262	64	57	417	*3,73*
	industrial	15	3	8	3	29	*3,57*
	agriculture	8	23	12	37	80	*15,94*
	forest	155	120	184	213	672	*15,66*
	grassland	22	84	6	1	113	*-51,08*
	bare land						
	water		1	14	76	91	*0,00*

In the *Overall Growth* scenario the urban is pushed by a significant urbanization force. The variation in the exposure of this class takes place in the HQ zones, while in the red and yellow zones it remains unchanged. The exposed surface is so distributed: 34 ha in the red zones, 262 ha in the yellow zones, 70 ha in the HQ30 and 65 in the HQ31-100. The overall exposed urban surface amount at 431 ha, increasing by 7.2 % since 2006. The exposed industrial land shows relatively lower surfaces, but the relative variation with 2006 is double as the urban (+ 14.3 %). Yellow zones and HQ31-100 remain unvaried (both 3 ha), while the exposed land portion in the red zone and in the HQ30 increases – 16 ha in the red zones and 10 ha in the HQ30. The agriculture shows tremendous variations from the exposed units in 2006. With no restriction in 2030 the exposed agricultural land distribution is as follows: 21 ha in the red zones, 84 ha in the yellow zones, 13 ha in the HQ30 and 35 ha in theHQ31-100. The overall exposed land increased by 121.7 % compared to 2006. Forest exposure to natural hazards increased form 2006 by 8.3 %, having 143 ha in the red zones, 97 ha in the yellow zones, 181 ha in the HQ30 and 208 ha in the HQ31-100. The grassland exposure decreases strongly since 2006 (-71.4 %). There are no units of grassland in the HQ zones, while the red and yellow zones account respectively for 20 and 46 ha of grassland.

In the *Overall Competition* the urbanization push is a little lower. The exposed urban in the red and yellow zones and in the HQ30 is the same as the previously shown scenario – respectively 34, 262 and 70 ha. The HQ30-100 exposed urban area decreases by 4 ha in comparison to the Growth scenario (61 ha are exposed). The overall variation with 2006 is +6.2 %. The industrial class overall exposure compared to 2006 increases by a 7.1 % and the distribution in the four categories is: 15 ha in the red zones, 3 ha in the yellow zones, 9 ha in the HQ30 and 3 ha in the HQ31-100. The agricultural land with respect to 2006 varies by a +95.7 %. The distribution in the four hazard zones accounts for 19 ha in the red zones, 64 ha in the yellow zones, 13 ha in the HQ30 and 39 ha in the HQ31-100. Forest is exactly the same as in the previous scenario. The exposed grassland decreases from 2006 by 61 %; in the red zones there are 22 ha and in yellow zones 68 ha, while the HQ zones have no exposed grassland area. Bare land and water show no variation.

Overall security. The exposed urban area increases by 3.5 % from 2006. The exposed urban is so distributed among the four hazard zones: 34 ha in the red zones, 262 ha in the yellow zones, 62 ha in the HQ30 and 58 in the HQ31-100. The industrial remains unvaried from the previously explained scenario. The exposed agriculture increases by a 58 % from 2006, but comparing the relative change in the period 2006-2030 in the other scenarios it is clear how this rate has been decreasing. 11 ha are located in the red zones, 37 ha in the yellow zones, 19 ha in the HQ30 and 42 ha in the HQ31-100. The forest exposure increases from 2006 by 13.9 %. This rate is 1.75 times bigger than in the other scenarios, meaning than forest occupies exposed land previously allocated as agriculture and urban mainly. The exposed grassland decreases from 2006 with a rate of -59 %, more or less the same as in the other scenarios. The exposed portion of this class is located in the red and yellow zones, 22 and 72 ha respectively. Bare land and water show no variation.

Overall Risk. The exposed urban area grows from 2006 by 3.7 %. In the red zones are located 34 ha, in the yellow zones 262 ha, in the HQ30 64 ha and in the HQ31-100 57 ha. The exposed industrial increases form 2006 by 3.6 % - the rate is the half than in the previous two scenarios. The change is happening in the HQ30 (8 ha). The rate of change in the exposure from 2006 in the agriculture is 15.9 %, significantly lower with respect to the other scenarios. 8 ha of this class are located in the red zones, 23 ha in the yellow, 12 in the HQ30 and 37 in the HQ31-100. The exposed forest grows from 2006 by 15.7 %. In the red zones are located 155 ha of forest, in the yellow 120 ha, in the HQ30 184 ha and in the HQ31-100 213 ha. Exposed grassland decreases from 2006 by 51 %, having 22 ha in the red, 84 in the yellow zones, 6 ha in the HQ30 and 1 in the HQ31-100 – before in the HQ there was no grassland. Bare land and water show no variation.

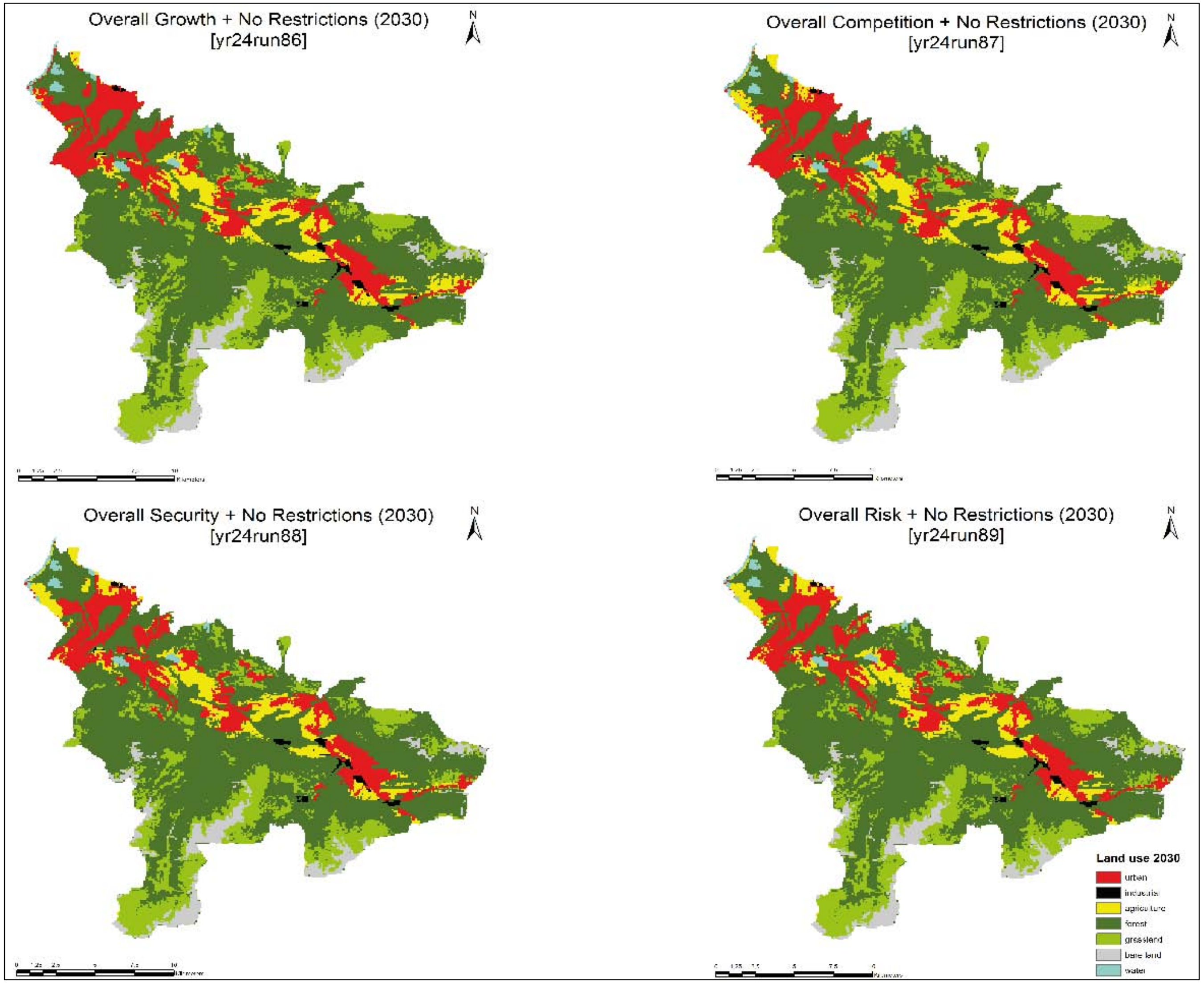

Figure 26. Outcome maps of the No Restrictions configuration in the four scenarios.

Restriction Light

In the Tab. 21 the effect of the introduction of restrictive policies in the natural protected areas (Natura 2000, natural parks, etc.) on the exposure to natural hazards can be observed. The cross-check procedure aims at assessing the amount of land falling under the hazard zones. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask.

Table 21. Summary tab for the Restriction Light configuration. The four spatial scenarios and the surfaces under hazard of each single land use class are displayed divided in the four zones – red and yellow zones, HQ30 and HQ31-100. The second last column shows the sum of the land threatened by hazards for each class. The delta_% column is the relative change of exposed land in comparison with 2006.

		Restriction Light					
	[ha]	**red**	**yellow**	**HQ30**	**HQ31-100**	**tot**	**delta_%**
GRO	***urban***	34	262	64	58	418	*3,98*
	industrial	16	3	10	3	32	*14,29*
	agriculture	18	83	13	35	149	*115,94*
	forest	143	99	181	208	631	*8,61*
	grassland	23	45	6	7	81	*-64,94*
	bare land						
	water		1	14	76	91	*0,00*
COMP	***urban***	33	248	64	58	403	*0,25*
	industrial	16	17	7	3	43	*53,57*
	agriculture	18	58	16	35	127	*84,06*
	forest	142	94	181	208	625	*7,57*
	grassland	25	75	6	7	113	*-51,08*
	bare land						
	water		1	14	76	91	*0,00*
SEC	***urban***	33	263	63	58	417	*3,73*
	industrial	16	3	10	3	32	*14,29*
	agriculture	18	28	12	35	93	*34,78*
	forest	142	131	183	208	664	*14,29*
	grassland	25	67	6	7	105	*-54,55*
	bare land						
	water		1	14	76	91	*0,00*
RISK	***urban***	34	262	64	58	418	*3,98*
	industrial	15	3	8	3	29	*3,57*
	agriculture	7	24	14	35	80	*15,94*
	forest	152	119	182	208	661	*13,77*
	grassland	26	84	6	7	123	*-46,75*
	bare land						
	water		1	14	76	91	*0,00*

Overall Growth. The introduction of the restriction measures decrease the growth rate of the exposed urban area (+4 % form 2006). The pixel distribution is as follows: 34 and 262 ha are in the red and yellow zones, like in 2006; 64 and 58 ha are in the HQ30 and HQ31-100. The restrictions do not influence the increasing exposure of the industrial class, which is the same as in the no restrictions configuration (+14.3 %). The exposed agriculture rate increases by 115.9 % from 2006. In the red zones are located 18 ha, in the yellow 83 ha, in the HQ30 13 ha and in the HQ31-100 35 ha. The relative change in the exposed forest from 2006 is +8.6 %. The exposed surfaces are so distributed, 143 ha in the red zones, 99 ha in the yellow zones, 181 ha in the HQ30 and 208 ha in the HQ31-100. The grassland overall exposure decreases by a 67.9 % compared to 2006. In the red zones are located 23 ha of forest, in the yellow 45 ha, in the HQ30 6 ha and in the HQ31-100 are located 7 ha. Bare land and water show no variation.

Overall Competition. In this scenario and with light restriction the exposed urban class remains almost unvaried with respect to the 2006 (+0.25 %). 53.6 % more industrial areas are exposed to natural hazards. This peak is quite strange and even less explainable; the only logic explanation that could be used is that this result is an artefact of the model. Like in 2006, 7 and 3 ha are in the HQ30 and in the HQ31-100 respectively. 16 ha are in the red and 17 ha in the yellow zones. 84.1 % more agriculture is threatened by natural hazards, with 18 ha in the red zones, 58 ha in the yellow zones, 16 ha in the HQ30 and 35 ha in the HQ31-100. The relative change in the exposed forest form 2006 is +7.6 % and 142 ha are located in the red zones, 94 ha in the yellow zones, 181 ha in the HQ30 and 208 ha in the HQ31-100. 51.1 % less grassland are exposed to natural hazards: 25 and 75 ha are in the red and yellow zones respectively, 6 ha in the HQ30 and 7 ha in the HQ31-100. Bare land and water show no variation.

Overall Security. 3.7 % more urban areas are exposed to natural hazards. 33 ha are located in the red zones, 263 ha in the yellow zones, 63 ha in the HQ30 and 58 ha in the HQ31-100. The industrial rate of change in the exposure with respect to 2006 is like in the *Overall Growth* (+14.3 %). The exposed surfaces in the yellow zones and HQ31-100 stay constant, while it increases slightly in the red zones (16 ha) and in the HQ30 (10 ha). 34.8 % more agriculture are endangered – less than half of the rate if the *Overall Competition*. 18 ha are located in the red zones, 28 ha in the yellow zones, 12 ha in the HQ30 and 35 ha in the HQ31-100. The rate of change in exposure of forest is almost the double with respect to the previous scenarios. 142 ha in the red zones, 131 ha in the yellow zones, 183 ha in the HQ30 and 208 ha are in the HQ31-100. The grassland overall exposure decreases by a 54.6 %, having 25 ha in the red zones, 67 ha in the yellow, 6 and 7 ha in the HQ30 and HQ31-100 respectively. Bare land and water show no variation.

Overall Risk. Almost 4 % more of urban areas are threatened by natural hazards. Within the exposed area 34 ha were counted in the red zones, 262 ha in the yellow zones (as in 2006), 64 ha in the HQ30 and 58 ha the HQ31-100. The industrial overall exposure change rate is + 3.6 %. The threatened surface are the same as in 2006 in the red and yellow zones and in the HQ31-100; the only change takes place in the HQ30 (8 ha). The rate of change of agriculture in this scenario is half of the one in the previous scenario (+15.9 %), having 7 ha in the red zones, 24 ha in the yellow zones, 14 ha in the HQ30 and 35 ha in the HQ31-100. 13.8 % more forests are exposed; 152 ha are located in the red zones, 119 ha in the yellow zones, 182 ha in the HQ30 and 208 ha in the HQ31-100. The grassland overall exposure decreases by a 46.8 %. The exposed surfaces in the four hazard zones are: 26 ha in the red zones, 84 ha in the yellow zones, 6 and 7 ha respectively in the HQ30 and HQ31-100. Bare land and water show no variation.

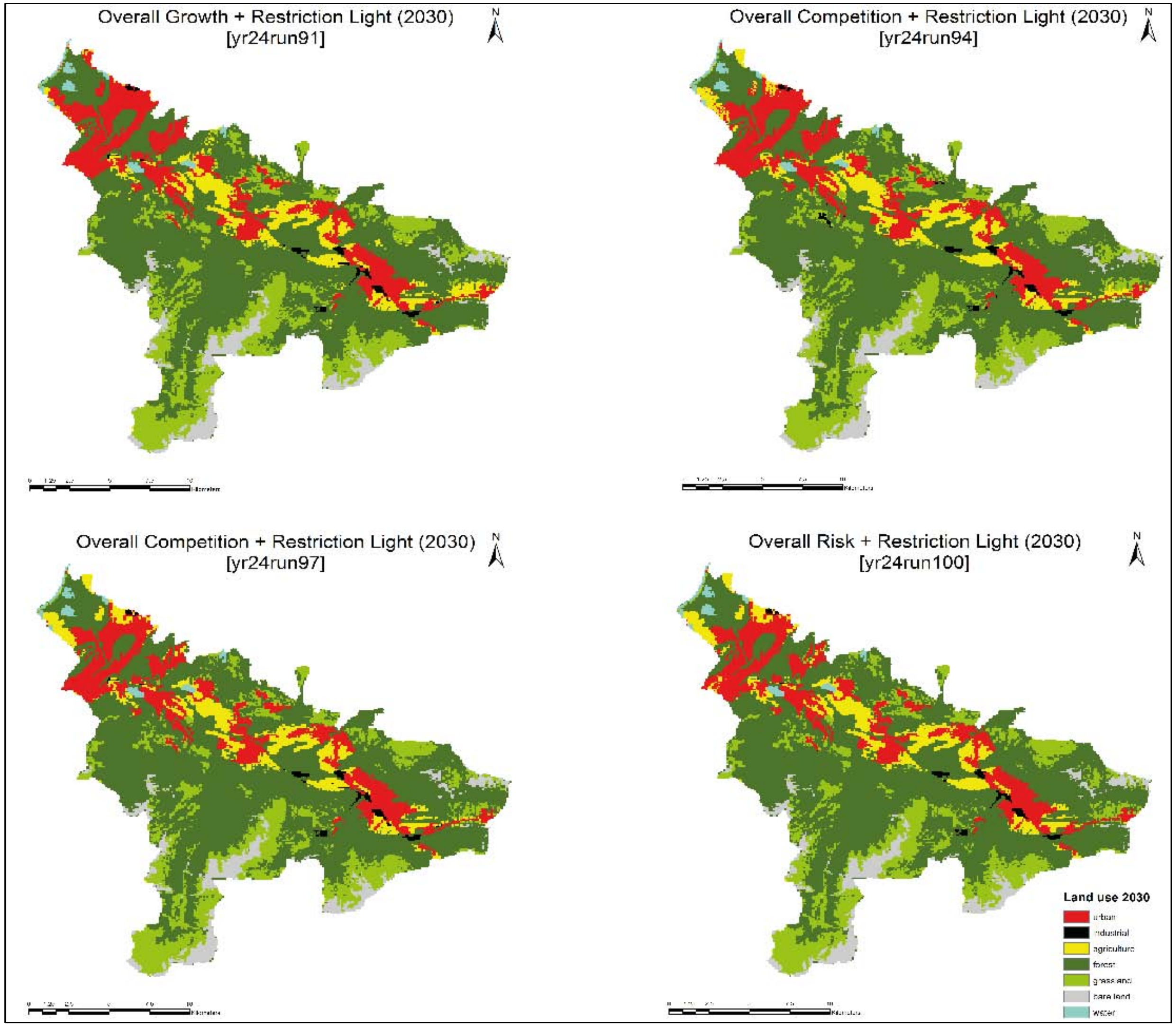

Figure 27. Outcome maps of the Restriction Light configuration in the four scenarios.

Restriction Medium

In the Tab. 22 the actual spatial policy and its effects on the exposure were tested. The policy bans from any further development the natural areas, the red zones and part of the HQ30. The cross-check procedure aims at assessing the amount of land falling under the hazard zones. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask.

Table 22. Summary tab for the Restriction Medium configuration. The four spatial scenarios and the surfaces under hazard of each single land use class are displayed divided in the four zones – red and yellow zones, HQ30 and HQ31-100. The second last column shows the sum of the land threatened by hazards for each class. The delta_% column is the relative change of exposed land in comparison with 2006.

				Restriction Medium			
	[ha]	**red**	**yellow**	**HQ30**	**HQ31-100**	**tot**	**delta_%**
GRO	***urban***	34	262	57	58	411	*2,24*
	industrial	15	3	9	3	30	*7,14*
	agriculture	12	82	12	35	141	*104,35*
	forest	136	89	182	208	615	*5,85*
	grassland	37	56	14	10	117	*-49,35*
	bare land						
	water		1	14	76	91	*0,00*
COMP	***urban***	34	262	57	58	411	*2,24*
	industrial	15	3	9	3	30	*7,14*
	agriculture	11	63	13	35	122	*76,81*
	forest	137	91	181	208	617	*6,20*
	grassland	37	73	14	7	131	*-43,29*
	bare land						
	water		1	14	76	91	*0,00*
SECUR	***urban***	34	256	57	58	405	*0,75*
	industrial	15	9	7	3	34	*21,43*
	agriculture	8	47	13	32	100	*44,93*
	forest	141	120	183	211	655	*12,74*
	grassland	36	60	14	7	117	*-49,35*
	bare land						
	water		1	14	76	91	*0,00*
RISK	***urban***	34	255	57	58	404	*0,50*
	industrial	15	10	7	3	35	*25,00*
	agriculture	8	41	14	35	98	*42,03*
	forest	141	120	182	208	651	*12,05*
	grassland	36	66	14	7	123	*-46,75*
	bare land						
	water		1	14	76	91	*0,00*

Overall Growth. 2.2 % more urban are exposed to natural hazards compared to 2006. Red and yellow zones remain unchanged, while in the HQ30 and HQ31-100 are located 57 and 58 ha of urban areas. The urban development, being here restricted in certain areas, happens at the disadvantage of the grassland. The exposure of the industrial raises by 7.1 %, like in the No Restrictions configuration. The change from 2006 in the four hazard zones takes place only in the HQ30 (9 ha). The agriculture overall exposure increases by a 104.3 %, having 12 ha in the red zones, 82 ha in the yellow zones, 12 ha in the HQ30 and 35 ha in the HQ31-100. The rate of change in the exposure of forest is 5.9 %. There are 136 and 89 ha in the red and yellow zones, and 182 and 208 ha in the HQ30 and HQ31-100. 49.4 % less grassland is exposed: 37 ha are in the red zones, 56 ha in the yellow, 14 ha in the HQ30 and 10 ha in the HQ31-100. Bare land and water do no change in the exposure in the period 2006-2030.

Overall Competition. The urban overall exposure increases by 2.2 % form 2006, with no variations from 2006 in the red and yellow zones, and 57 and 58 ha in the HQ30 and HQ31-100 – like in the previous scenario. 7.1 % more of industrial are exposed to natural hazards. There are no variations from 2006, besides in the HQ30 (from 7 to 9 ha). The agricultural overall exposure change rate is 76.8 %, having 11 ha in the red zones, 63 in the yellow zones, 13 ha in the HQ30 and 35 ha in the HQ31-100. 6.2 % more forest are exposed: 137 and 91 ha are in the red and yellow zone respectively; 181 and 208 ha are in the HQ30 and HQ31-100. The grassland overall exposure decreases from 2006 by 43.3 %. There are 37 ha in the red zones, 73 ha in the yellow zones, 14 ha in the HQ30 and 7 in the HQ31-100. Bare land and water do no change in the exposure in the period 2006-2030.

Overall Security. Only 0.8 % more urban area are threatened by natural hazards. With these scenario and restrictions configuration the rate of change in the exposure shrinks significantly: the red zones are the same as in 2006; the HQ30 have 57 ha of urban and the hQ31-100 58 ha. In the yellow zones for the first time in this class, there is a decrease in the exposed surface (256 ha). The conversion of urban to industrial is the only allowed, thus the industrial gained 6 ha in the yellow zones (9 ha), while the other hazard zones remain unvaried from 2006. The overall industrial exposure change is 21.4 %. 31 more ha (+44.9 %) of agriculture are exposed: 8 ha are located in the red zones, 47 ha in the yellow zones, 13 ha in the HQ30 and 32 ha in the HQ31-100. The 12.7 % more forest are under the threat of hazards; the surfaces are distributed in the four categories as follows: 141 ha are in the red zones, 120 ha in the yellow zones, 183 ha in the HQ30 and 211 ha are in the HQ31-100. The grassland overall exposure change rate is -49.4 %, having 36 ha in the red zones, 60 ha in the yellow zones, 14 ha in the HQ30 and 7 in the HQ31-100. Bare land and water do no change in the exposure in the period 2006-2030.

Overall Risk. The exposed urban area is 0.5 % bigger than in 2006. The red zones remain unvaried, while in the HQ zones this class increases its surface (HQ30 57 ha; HQ31-100 58 ha). The urban surface in the yellow zones shrinks to 255 ha, which are again taken by the industrial class (yellow zones 10 ha). The overall exposure change from 2006 of the industrial is +25 %. + 42 % of agricultural lands are under exposure: 8 ha are in the red zones (same as in 2006), 41 ha in the yellow zones, 14 ha in the HQ30 and 35 ha in the HQ31-100. 70 more ha (+ 12.1 %) of forest are exposed: 141 are in the red zones, 120 in the yellow zones, 182 in the HQ30 and 208 in the HQ31-100. 46.8 % less grassland is on hazarded zones; the grass surface is distributed among the four classes as follows: 36

ha in the red zones, 66 in the yellow, 14 in the HQ30 and 7 in the HQ31-100. Bare land and water do no change in the exposure in the period 2006-2030.

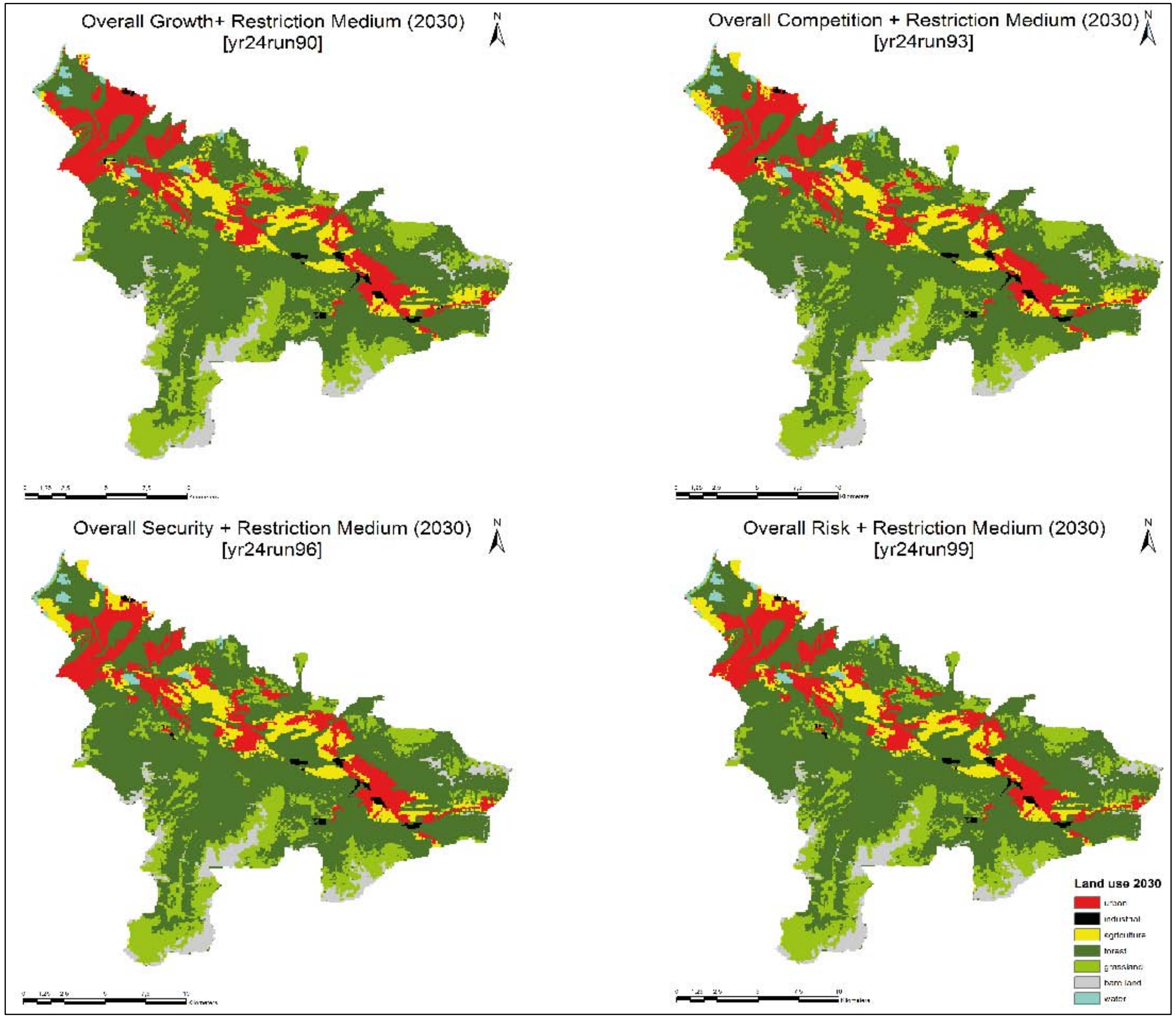

Figure 28. Outcome maps of the Restriction Medium configuration in the four scenarios.

Restriction Heavy

The effects of a stronger spatial restrictive policy are observable in the Tab. 23. The building ban is prohibited here in the natural areas, red and yellow zones and HQ100, thus the maximum extent of the actual hazard zonation is classified as restricted, hence not convertible. The cross-check procedure aims at assessing the amount of land falling under the hazard zones. We performed an extraction using the hazard zonation as a mask and getting the pixels of the different land use categories that lay under this mask.

Table 23. Summary tab for the Restriction Heavy configuration. The four spatial scenarios and the surfaces under hazard of each single land use class are displayed divided in the four zones – red and yellow zones, HQ30 and HQ31-100. The second last column shows the sum of the land threatened by hazards for each class. The delta_% column is the relative change of exposed land in comparison with 2006.

		Restriction Heavy					
	[ha]	**red**	**yellow**	**HQ30**	**HQ31-100**	**tot**	**delta_%**
GRO	***urban***	34	262	56	57	409	*1,74*
	industrial	15	3	8	3	29	*3,57*
	agriculture	10	40	13	22	85	*23,19*
	forest	135	79	182	208	604	*3,96*
	grassland	40	108	15	21	184	*-20,35*
	bare land						
	water		1	14	76	91	*0,00*
COMP	***urb***	34	262	56	57	409	*1,74*
	ind	15	3	8	3	29	*3,57*
	agr	9	32	13	22	76	*10,14*
	for	135	83	182	208	608	*4,65*
	grass	41	112	15	21	189	*-18,18*
	bare						
	wat		1	14	76	91	*0,00*
SECUR	***urban***	34	262	56	57	409	*1,74*
	industrial	15	3	8	3	29	*3,57*
	agriculture	9	24	13	22	68	*-1,45*
	forest	135	92	182	208	617	*6,20*
	grassland	41	111	15	21	188	*-18,61*
	bare land						
	water		1	14	76	91	*0,00*
RISK	***urban***	34	262	56	57	409	*1,74*
	industrial	15	3	7	3	28	*0,00*
	agriculture	8	27	13	22	70	*1,45*
	forest	137	90	183	208	618	*6,37*
	grassland	40	110	15	21	186	*-19,48*
	bare land						
	water		1	14	76	91	*0,00*

Overall Growth. Between 2006 and 2030, 7 ha (+1.7 %) more urban areas are exposed to natural hazards. The increase takes place in the HQ30 (56 ha) and in the HQ31-100 (57 ha). The industrial exposure increases only by 1 ha (+3.6 %) in the HQ30. 23.2 % more of agriculture is located in hazarded zones, namely 10 ha in the red zones, 40 ha in the yellow zones, 13 ha in the HQ30 and 22 ha in the HQ31-100. 23 more ha (+4 %) of agriculture are located in the red zones (135 ha), in the yellow zones (79 ha), in the HQ30 (182 ha) and in the HQ31-100 (208 ha). The exposed grassland is 20.4 % smaller than in 2006. In the red zones are located 40 ha of grassland, in the yellow 108, in the HQ30 15 and in the HQ31-100 21. Bare land and water show no change in the exposure in the period 2006-2030.

Overall Competition. In this scenario, the change in the exposure of the urban and industrial is the same as in the previous scenario (+1.7 % and +3.6 %). +7 ha (+10.1 %) of agriculture are in exposed areas; 9 ha are in the red zones, 32 ha in the yellow zones, 13 in the HQ30 and 22 in the HQ31-100. The exposed forested area is 4.7 % bigger than in 2006, having 135 ha in the red zones, 83 ha in the yellow zones, 182 ha in the HQ30 and 208 ha in the HQ31-100. The overall exposure of the grassland decreases by the 18.2 % - 41 ha are located in the red zones, 112 in the yellow zones, 15 in the HQ30, 21 in the HQ31-100. Bare land and water show no change in the exposure in the period 2006-2030.

Overall Security. Also in this scenario, the change in the exposure of the urban and industrial is the same as in the previous scenario (+1.7 % and +3.6 %). The exposed are of the agriculture decreases here by 1 ha (-1.5 %). It is observable that the exposed surface in the red and yellow zones increases (respectively 9 ha and 24 ha), while in the HQ zones it decreases (13 and 22 ha in the HQ30 and HQ31-100). The overall exposed forested area increase by the 6.2%, having 135 ha in the red zones, 92 ha in the yellow zones, 182 ha in the HQ30 and 208 ha in the HQ31-100. The exposed grassland decreases by 18.6 %: 41 ha are located in the red zones, 111 ha in the yellow zones, 15 ha in the HQ30 and 21 ha in the HQ31-100. Bare land and water show no change in the exposure in the period 2006-2030.

Overall Risk. In this scenario, the change in the exposure of the urban is the same as in the previous scenario. The industrial shows no variation in the exposure from 2006. The surface of agriculture exposed to natural hazards increases by 1 ha (+1.5 %): 8 ha are in the red zones, 27 in the yellow, 13 ha in the HQ30 and 22 ha in the HQ31-100. The exposed forest increase by 6.4 %, with 137 ha located in the red zones, 90 in the yellow zones, 183 in the HQ30 and 208 in the HQ31-100. The overall exposure of the grassland decreases by 19.5 % (40 ha are in the red zones, 110 in the yellow zones, 15 in the HQ30 and 21 in the HQ31-100). Bare land and water show no change in the exposure in the period 2006-2030.

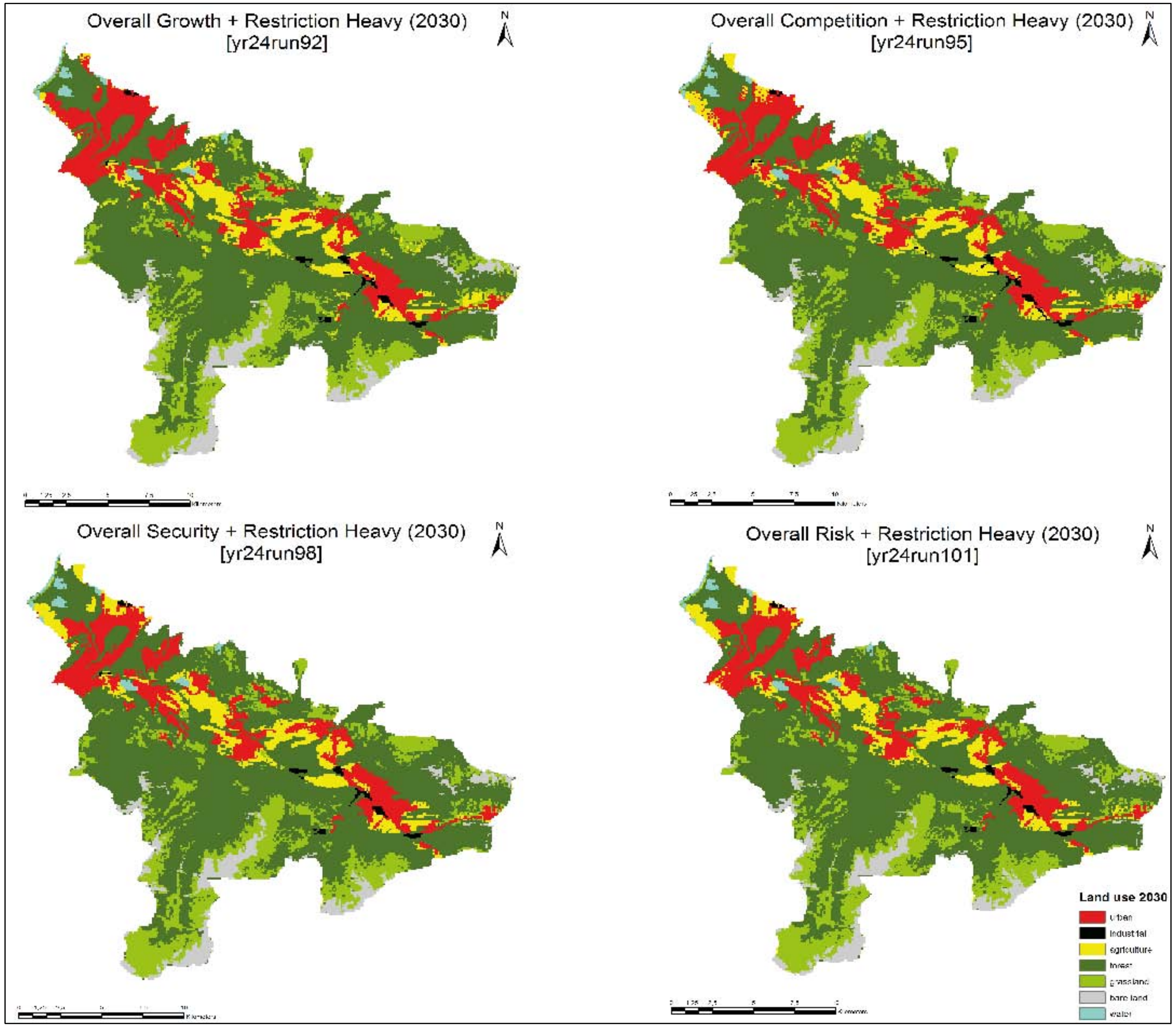

Figure 29 Outcome maps of the Restriction Heavy configuration in the four scenarios.

Discussion of the results

In the scenario *Overall Growth* the exposure of urban class remains constant in the red and yellow zones by the WLV, with all the four restriction configurations; in fact it varies in the HQ zones with values ranging from 113 to 135 ha. The valley bottom is the most suitable place for urban development; this is why the new exposed urban units popped up in the HQ areas which are located along the river (e.g. de Moel & Aerts 2011). The findings of the study by Cammerer et al. (2013) in another area of the Austrian Alps states the contrary: the spatial regulation policies have no influence on the building development in floodable areas (HQ zones), but more the areas interested by torrential and other alpine hazards (red and yellow zones). Generally, in our case, the introduction of restrictive policies act as expected, hindering the further develop of urban areas inside the hazard zones. The highest impact is represented by the introduction of the Restriction Light, namely the natural protected areas. However, most of the urban development is happening in areas not interested by natural hazards (Cammerer & Thieken 2013), taking land mostly from the grassland. In other words, the urban development, being here restricted in certain areas, happens outside the hazard zones mainly at the disadvantage of the grassland (Tab. 24).

Regarding the industrial areas in all the scenarios – excluding one case with shows an anomalous outcome: *Overall Competition*/Restriction Light/yellow zones – the changes in the exposure take place in the HQ30 and in the red zones. This dynamics is due to the preference of development of new industrial areas which often takes place in the neighborhood to infrastructures and already existing industrial areas (e.g. Verburg et al. 2002; Cammerer et al. 2013), or at the margin of the urban areas. In fact, generally the new industrial areas are the result of the conversion of suburban agricultural surfaces (Xu et al. 2013). In two cases with Restriction Medium and scenarios *Overall Security* and *Risk* a small portion of the urban is converted into industrial. Only in the *Overall Growth* the more restrictive are the policies the less industry results to be exposed. In the other scenarios the outcomes are more fluctuating, without showing a precise trend. For example, although the total surface of the industrial is 240 ha in the growth scenario and 212 ha in the risk scenario, in the latter are exposed 35 ha while in the first 30 ha, with Restriction Medium (Tab. 24).

Agriculture shows also particular dynamics within the scenarios and the different restriction configuration: even though the total surface of this class shrinks in all four scenarios (from -3.5 % to -1 %), its exposure changes considerably. In the growth and competition scenarios the exposed agricultural surface is almost doubling from 2006 in all the cases, except with heavy restrictions. For instance, with no restriction and growth scenario, 664 ha of low altitude grassland are converted into agriculture, increasing its share of exposed surface, especially in the red and yellow zones. Agriculture loses its surface mostly in favor of urban, industrial and forest (-729 ha); this surface is though not interested by any natural hazard (Tab. 24).

Forest total surface increases slightly across the four spatial scenarios – in the literature forest claim of abandoned land is more pronounced (e.g. Tappeiner et al. 2008; Price et al. 2015) – resulting from the conversion of agriculture, grassland and bare land (almost negligible); in the growth and competition scenarios the exposure dynamics are very much the same, ranging from +8.3 % to ca. +4.3 %, while in the security and risk scenarios the exposure change form 2006 are ranging from ca. +14.8 % to ca. +6.3 % (Tab. 24).

Grassland surfaces has been strongly affected by the mountain abandonment happening in the last fifty years (e.g. Tappeiner et al. 2008). With increasing restriction the grassland shows a less decreasing rate of exposed land from 2006. This means that the exposed grassland it always decreasing from 2006, but the stronger are the restrictions the less grassland is converted, therefore the proportion of exposed surface decreases lesser as with no restriction. In fact a big part of this class outside the restricted areas, has been eaten by urbanization (e.g. Price et al. 2015), agriculture and forest, due to its easy conversion and to the scenario trend (average of -11.7 % in the four scenarios). Along the four scenario, the non-exposed grassland decreases with growing restrictions. We observed an interesting inverse symmetry in the growth scenario between urban and grassland: while the exposed portion of the first decreases with higher restrictions, the latter increases, showing in 2006 a highly exposed surface, which with no restrictions is easily occupied by the urban – which is geographically adjacent – while with strong restrictions the urbanization development has less allowed space to grow into the grassland (Tab. 24).

Table 24. Relative change of exposed land in comparison with 2006, across the four spatial scenarios and with the four restriction configurations.

Restrictions		***No***	***Light***	***Medium***	***Heavy***
GRO	***urban***	7,2	4,0	2,2	1,7
	industrial	14,3	14,3	7,1	3,6
	agriculture	121,7	115,9	104,3	23,2
	forest	8,3	8,6	5,9	4,0
	grassland	-71,4	-64,9	-49,4	-20,3
COMP	***urban***	6,2	0,2	2,2	1,7
	industrial	7,1	53,6	7,1	3,6
	agriculture	95,7	84,1	76,8	10,1
	forest	8,3	7,6	6,2	4,6
	grassland	-61,0	-51,1	-43,3	-18,2
SEC	***urban***	3,5	3,7	0,7	1,7
	industrial	7,1	14,3	21,4	3,6
	agriculture	58,0	34,8	44,9	-1,4
	forest	13,9	14,3	12,7	6,2
	grassland	-59,3	-54,5	-49,4	-18,6
RISK	***urban***	3,7	4,0	0,5	1,7
	industrial	3,6	3,6	25,0	0,0
	agriculture	15,9	15,9	42,0	1,4
	forest	15,7	13,8	12,0	6,4
	grassland	-51,1	-46,8	-46,8	-19,5

Observing the results on a land use class level, across the four scenarios and with the four restriction configurations, the response of the model to the introduction of the restriction policies can be assessed. It is clearly noticeable how the influence of the restrictive policies leads to have the same outcomes across the four scenarios (Fig. 30).

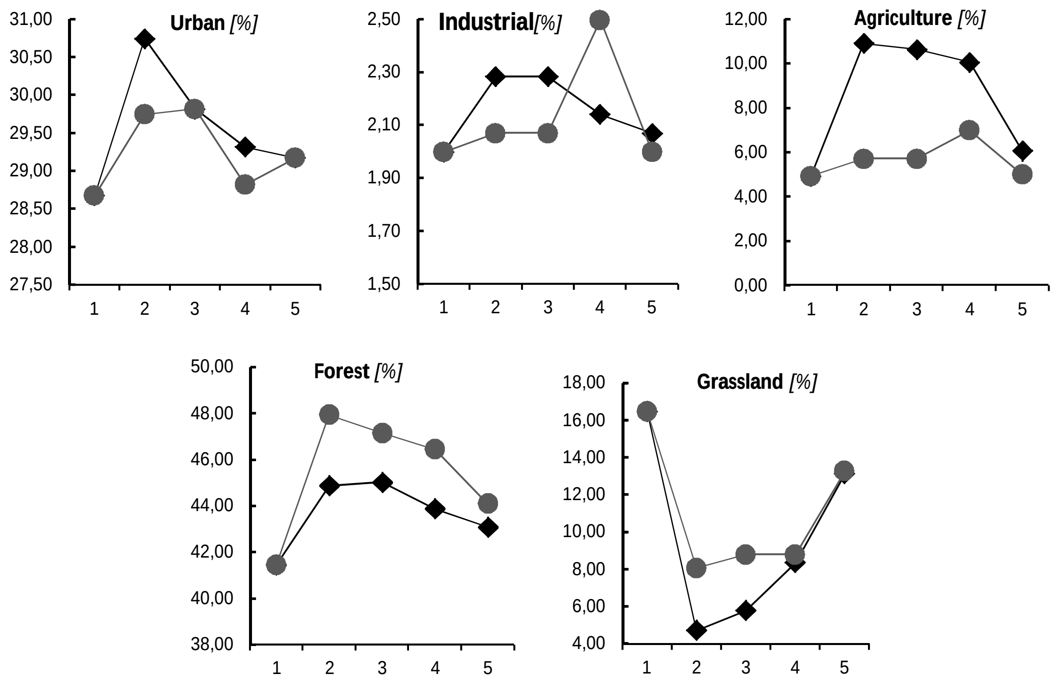

Figure 30. On the vertical axis the rate between the exposed area of the considered land use class and the total exposed area in the Ill-Walgau (1402 ha). On the horizontal axis: "1" is the 2006 rate; "2", "3", "4", "5" are the rate in 2030 with increasing restrictions – "2" is with no restrictions, "5" is heavy restriction. The black line with the squared indicators represents the Overall Growth scenario, while the grey with dots is the Overall Risk scenario.

In the Fig. 30 the dynamics of the two extremes scenarios are well visible. The dots are the ration between the exposed areas of the considered land class with the total exposed area, which is fixed according to the hazard zonation. The dynamic of the exposed land portion of each land use class is shown, allowing comparing the initial situation in 2006 ("1") with the simulated results in 2030 with the different restriction configurations ("2", "3", "4", "5"). With growing restrictions the two opposite scenario tend to converge on more or less the same result, therefore allow to formulate the following statement: the resulting spatial pattern of the study area becomes almost un-dependent from the scenario trends – scenarios are not trend decided on a local scale, are rather autonomous global/continental dynamics – while the spatial policies, implemented by the local authorities, might affect these pattern and dynamics in a positive way (Verburg & Overmars, 2009). It could be a quite important element in the hand of the local planners willing to emancipate the landuse development in a certain area from any external or top-down trend. Assuming a better knowledge of the location characteristics handled by the local authorities, a bottom-up planning activity with the implementation of ad-hoc-generated planning tools is surely advisable in the context of mountain hazard exposure, rather than un-controllable top-down dynamics led by speculation. In other words, what the Fig. 7 says is that the spatial policies might have a strong hindering effect on the impact that a strong urbanization push, like the growth scenario, has on the exposure dynamics.

In the Fig. 31 the model responses to the different restriction policies are displayed in the two extreme scenarios *Overall Growth* and *Overall Risk,* for each land use class. The bars represent the land exposed to natural hazard in ha. The purple is the 2006 and in the scale of red are the three different restriction settings we have chosen. If we think at the spatial arrangement of the land use we could recognize that: the three classes which are more interesting for us under an socio-economic perspective (urban, industrial, agriculture) are located where the restricted areas are more present (along the river, bottom of the valley), and that's why with increasing restrictions there is a decrease in the exposed areas of these classes. While the grass show a diametrical opposite pattern. This is in line to the results from Price et al. (2015) where it is stated that, although the difficulties of modeling the socio-economic processes, the policy intervention do have an impact on land use changes; modeling these dynamics enables the policy makers to make informed decisions having in mind the outcomes that these choices might generate.

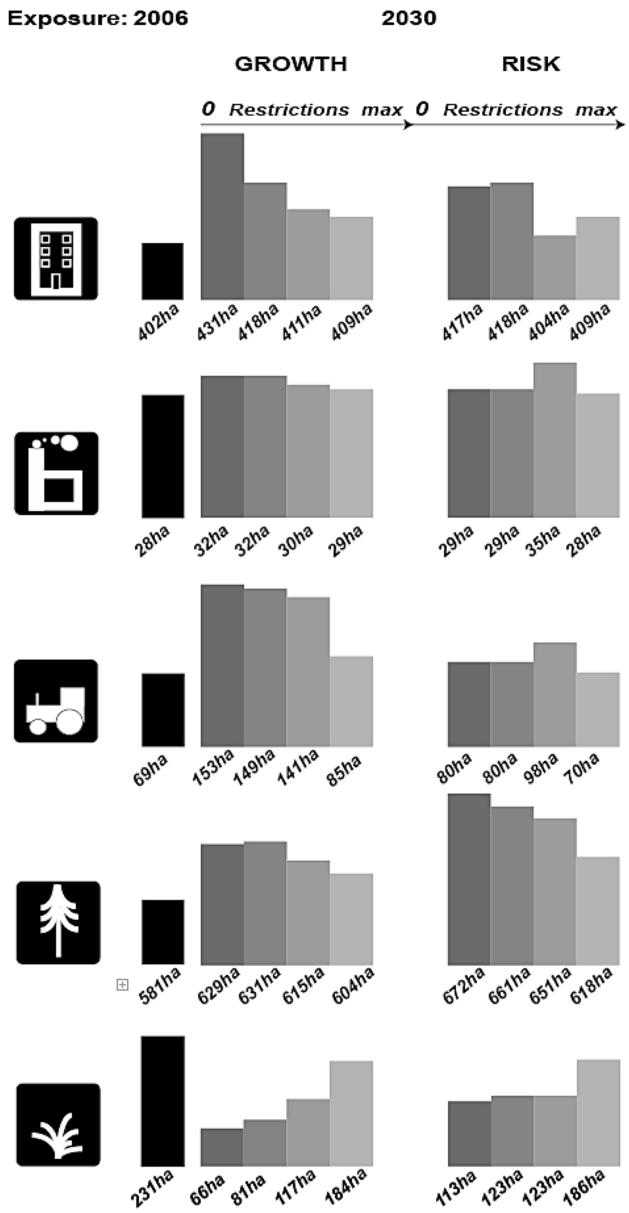

Figure 31. Model responses to the different restriction policies in the two extreme scenarios (Overall Growth and Overall Risk), for each land use class – represented by the pictograms in the order: urban, industrial, agriculture, forest, grassland. The bars represent the land exposed to natural hazards in ha. The purple is the 2006 and in the scale of red are the three different restriction settings we have chosen.

5.5 Sensitivity of the model to a reduced number of driving factors

In order to test the sensitivity of the model to the set of driving factors, two additional runs were made. From the results of the binary logistic regression were excluded the variables expressing the labour structure (enterprises and employees in the three sectors) and the five variables expressing the soil classification adopted from FAO. The drivers left in the equation are: population density, private housing percentage, distance to the station, distance to the city, yearly precipitation, distance from the school, distance from the street, aspect, elevation, the four categories of geology (lime stone, detrital formation, alluvial formation), and the six temperature ranges from -2° to 10° C annual average – for more information please see the section 4.4. The aim of this analysis is to test how a different set of driving factors might influence the model outcomes, and therefore how the incorporation of the explanatory drivers of change affects the results. The quality of the dataset and the way these data area expressed – results of the logit function – has still big gaps to be filled and a number of uncertainties are present (Verburg et al., 2013). The test runs were performed with the two opposite extreme scenarios *Overall Growth* and *Overall Risk*, using the No Restriction configuration.

Tab. 25, 26, 27 and 28 show the comparison with the reference simulations, done with the complete set of drivers and no restrictions, against the simulation implemented using nineteen drivers. On the left part of the table there are the land use classes and the relative identification codes; the column "30 drivers" shows the hectares per each land use class with the full set, while the column "19 drivers" shows the hectares simulated using the reduced set. The column "Delta_%" expresses the variation in percentage between the two simulated maps, at a class level.

5.5.1 Overall Growth

The urban class shows a decrease of 2.4 % of the area in the "19 drivers" simulation compared to the "30 drivers" one. The industrial increases its surface of a 12.7 %, while the agriculture shows a little variation (0.3 %). Forest changes its area by a +0.01 %, while water does not change at all, while grassland decrease by 0.1 % and the bare land increase by a 4.5 %. The first analysis is able to express just the magnitude of the change, referring in fact only to the quantification of the variation, while the location is not expressed (Tab. 25).

Most important in order to assess the impact of the driving factors on the simulated outcomes, is the location of the variation, namely where the changes from the two runs are happening, where are the hotspots, which classes are the most involved and why. Reading the Tab. 26 and with the help of the map (Fig. 32), it is possible to analyse these changes. The proper way to read the change map is the following: the light yellow pixels are the pixel where no change is happening; the scale of reds, from light to dark, expresses the changes along the classes.

Urban. 3884 ha (84.7 %) of urban stayed in the urban, meaning that the 2.4 % was lost. These 700 ha (ca. 15.3 %) were allocated to agriculture (698 ha) and to forest (2 ha). Looking at the Fig. 32 the changing surfaces can be spotted: the pixels allocated to agriculture and forest are located in the all in the lower part of the catchment (North-West), around the city of Feldkirch – actually those pixel in 2006 were mostly classified as agriculture. Removing the variables expressing labour the surroundings of the main city become more suitable for agriculture rather than urbanization. The labour structure variables were telling to the model that those areas around Feldkirch were more suitable for urbanization, while removing them the other factors prevailed.

Table 25. Comparison between the reference simulation, done with the complete set of drivers – overall growth scenario,no restrictions – and the simulation implemented using nineteen drivers. The land use classes and the relative identification codes are displayed; the column "30 drivers" shows the hectares per each land use class with the full set, while the column "19 drivers" shows the hectares simulated using the reduced set. The column "Delta_%" expresses the variation in percentage between the two simulated maps, at a class level.

		growth/no restr *[ha]*		
	code	***30 drivers***	***19 drivers***	***Delta_%***
urban	**0**	4584	4475	-2,4
industrial	**1**	236	266	12,7
agriculture	**2**	2327	2334	0,3
forest	**3**	18626	18627	0,01
grassland	**4**	6093	6084	-0,1
bare land	**5**	1797	1877	4,5
water	**6**	288	288	0,0

Table 26. The conversion column shows to which land use class the pixels of the simulation with nineteen drivers have been allocated in comparison with the reference simulation, in hectares and percentage.

Conversion		***ha***	***%***
urb	*0*	*3884*	*84,73*
urb to agr	0 to 2	698	*15,23*
urb to for	0 to 3	2	*0,04*
ind	*1*	*200*	*84,75*
ind to urb	1 to 0	21	*8,90*
ind to agr	1 to 2	15	*6,36*
agr	*2*	*1566*	*67,30*
agr to urb	2 to 0	459	*19,72*
agr to ind	2 to 1	65	*2,79*
agr to for	2 to 3	10	*0,43*
agr to grass	2 to 4	227	*9,76*
for	*3*	*18403*	*98,80*
for to urb	3 to 0	19	*0,10*
for to ind	3 to 1	1	*0,01*
for to agr	3 to 2	5	*0,03*
for to grass	3 to 4	161	*0,86*
for to bare	3 to 5	37	*0,20*
grass	*4*	*5695*	*93,47*
grass to urb	4 to 0	92	*1,51*
grass to agr	4 to 2	50	*0,82*
grass to for	4 to 3	189	*3,10*
grass to bare	4 to 5	67	*1,10*
bare	5	1773	*98,66*
bare to for	5 to 3	23	*1,28*
bare to grass	5 to 4	1	*0,06*
wat	6	288	*100,00*

Industrial. The allocation 84.8 % of the industrial remained industrial while the 8.9 (21 ha) and 6.4 % (15 ha) were allocated as urban and agricultural respectively. For the same reason as in the urban class, the labour structure was directing the model to the allocation of the industrial category. These pixels are located in areas that in 2006 were classified as agriculture and grassland, at the valley bottom along the main road.

Agriculture. The 67.3 % (1566 ha) of the agriculture were allocated in the same class. 459 ha (19.7 %) were allocated to urban, 65 ha (2.8 %) to industrial, due to the removal of the soil variables. These were agricultural and grass land areas in 2006 that were urbanized or converted to industry. These surfaces are located at the margin of agricultural areas. 10 ha of agriculture were allocated to forest (0.4 %) to forest, and 227 ha (9.8 %) to grassland. These areas were grassland in 2006 and mostly they remain unchanged, except for 10 ha of forest.

Forest. 18403 ha (99 %) were allocated to forest showing no change between the two simulations. The majority of the differences involved the grassland 161 ha (0.9 %) and bare land 37 ha (0.2 %); with the removal of the soil variables they remained in the 2006 respective classes. 19 ha (0.1 %) was allocated to urban, 1 ha (0.01 %) to industrial and 5 ha (0.03 %) to agriculture.

Grassland. 5695 ha of grassland remained unvaried (93.5 %). The biggest difference involves the forest, with 189 ha (3.1 %) that were not allocated to grassland like in the run with thirty drivers, but were allocated to forest. These pixels results mostly from grassland in 2006 that were converted to forest due partially from the soil variables and partially form the labour structure variables removal. In fact the pastures abandonment might lead to reforestation of some areas (e.g. Tappeiner et al. 2008). 92 ha were allocated as urban (1.5 %) – in 2006 these pixels were also classifies as grassland. The reason could be the same, pastures abandonment in settlement-suitable areas leads to urbanization. 50 ha (0.8 %) were allocated to agriculture; in 2006 they were classified as grassland. 67 ha (1.1 %) were allocated to bare land. These pixels are located in marginal area and in 2006 were mainly classifies as grassland.

Bare land. 98.7 % of the bare land remained in the same class. Only 23 ha (1.3 %) were converted to forest and 1 ha (0.06 %) to grassland.

Water remained unchanged.

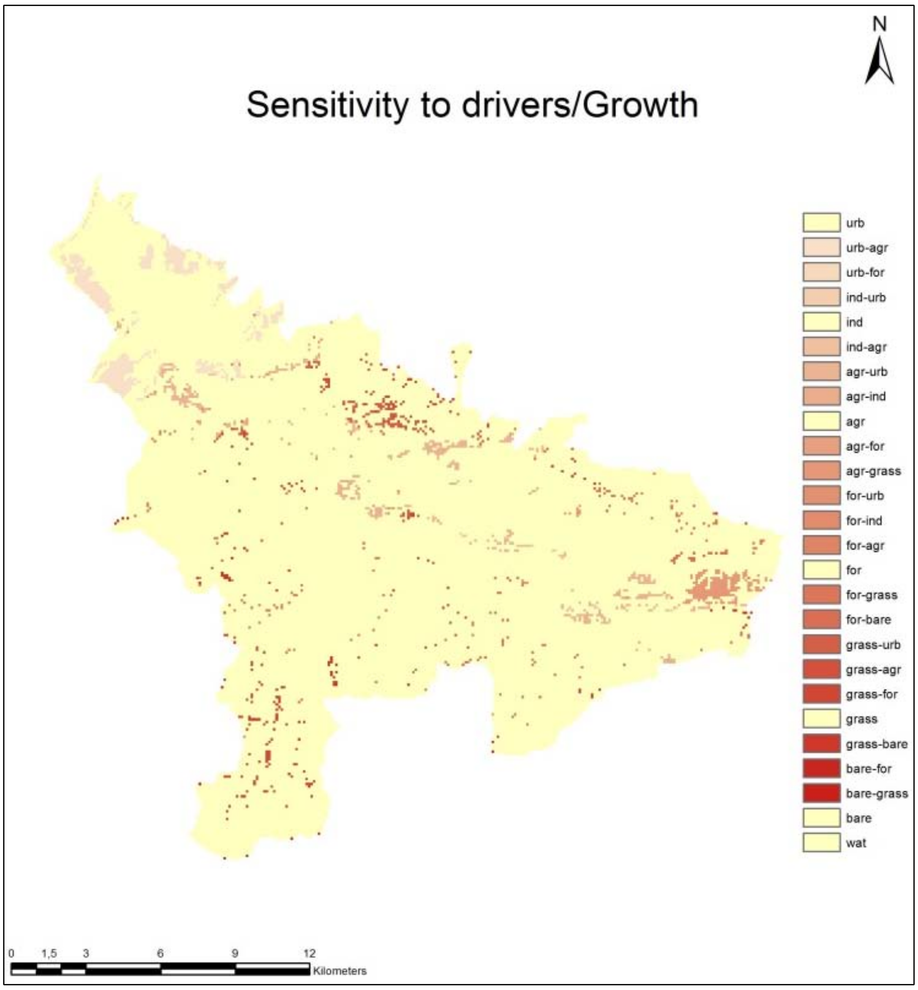

Figure 32. Map of change between the simulated map with the full set of variables and the simulated map with only nineteen drivers – overall growth scenario, no restrictions. The yellow pixels show the cells which did no experience any change; the scale of reds, shows the changes among the land use classes.

5.5.2 Overall Risk

In the urban there is a decrease (-0.9 %) in the area from the “30 drivers” simulated map and the “19 drivers” simulated map. The industrial decreases its surface by 6.1 % (13 ha). Forest and bare land increase their surface respectively by 0.2 % and 4.4 %, while in grassland and water there is a decrease of respectively 1.3 and 0.3 % (Tab. 27).

As already mentioned above, in order to assess the impact of the driving factors on the simulated outcomes, what is very important is the location of the variation, namely where are the hotspots of change, which classes are the most involved and how the new set of driving factors might have affected the new spatial pattern. Reading the Tab. 28 and with the help of the map, it is possible to analyse these changes. The proper way to read the change map (Fig. 33) is the following: the light yellow pixels are the pixel where no change is happening; the scale of reds, from light to dark, expresses the changes along the classes.

Table 27. Comparison between the reference simulation, done with the complete set of drivers – overall growth scenario, no restrictions – and the simulation implemented using nineteen drivers. The land use classes and the relative identification codes are displayed; the column “30 drivers” shows the hectares per each land use class with the full set, while the column “19 drivers” shows the hectares simulated using the reduced set. The column “Delta_%” expresses the variation in percentage between the two simulated maps, at a class level.

		risk/no restr *[ha]*		
	code	***30 drivers***	***19 drivers***	***Delta_%***
urban	**0**	4036	3999	-0,9
industrial	**1**	213	200	-6,1
agriculture	**2**	2369	2379	0,4
forest	**3**	19285	19324	0,2
grassland	**4**	5965	5888	-1,3
bare land	**5**	1796	1875	4,4
water	**6**	287	286	-0,3

Table 28. The conversion column shows to which land use class the pixels of the simulation with nineteen drivers have been allocated in comparison with the reference simulation in hectares and percentage.

conversion		***ha***	***%***
urb	*0*	*3814*	*94,50*
urb to agr	0 to 2	210	*5,20*
urb to for	0 to 3	12	*0,30*
ind	*1*	*200*	*93,90*
ind to urb	1 to 0	4	*1,88*
ind to agr	1 to 2	9	*4,23*
agr	*2*	*2084*	*87,97*
agr to urb	2 to 0	181	*7,64*
agr to for	2 to 3	95	*4,01*
agr to grass	2 to 4	9	*0,38*
for	*3*	*18902*	*98,01*
for to agr	3 to2	52	*0,27*
for to grass	3 to 4	289	*1,50*
for to bare	3 to 5	42	*0,22*
grass	*4*	*5589*	*93,70*
grass to agr	4 to 2	24	*0,40*
grass to for	4 to 3	289	*4,84*
grass to bare	4 to 5	63	*1,06*
bare	*5*	*1770*	*98,55*
bare to for	5 to 3	25	*1,39*
bare to grass	5 to 4	1	*0,06*
wat	*6*	*286*	*99,65*
wat to for	6 to 3	1	*0,35*

Urban. The 94.5 % of the urban was allocated in the same class (3814 ha). 210 (5.2 %) and 12 ha (0.3 %) were allocated to agriculture and forest, respectively. the pixels allocated to agriculture and forest are located in the all in the lower part of the catchment (North-West), around the city of Feldkirch. Removing the variables expressing labour the surroundings of the main city become more suitable for agriculture rather than urbanization. The labour structure variables were telling to the model that those areas around Feldkirch were more suitable for urbanization, while removing them other factors prevailed.

Industrial. 200 ha of the industrial were allocated to the same category (93.9 %). 1.88 and 4.9 % were allocated to urban and agriculture, respectively. For the same reason as in the urban class, the labour structure was directing the model to the allocation of the industrial category. These pixels are located in areas that in 2006 were classified as agriculture and grassland, at the valley bottom along the main road.

Agriculture. 88 % of the agriculture does not show any change between the two simulations. 181 ha (7.6 %) were urbanized, while 9 ha (0.4 %) were allocated to grassland – these cells were already grassland in 2006. 95 ha (4 %) were agricultural areas in 2006, that were converted into forest. The agriculture that were urbanized or afforested from agricultural lands in 2006, are located at the margin of agricultural areas.

Forest. 18902 ha of forest remained unchanged in the two simulations. 0.3 % (52 ha) of these surface was allocated to agriculture, resulting from the conversion of grassland in 2006. 289 ha (1.5 %) were allocated to grassland, coming either from forest or grassland in 2006. The 0.22 % was allocated to bare land – in 2006 these cells were classified as bare land. These dynamics are most probably due to random effect.

Grassland. 5589 ha were allocated to grassland as in the "30 drivers" simulation (93.7 %). 24 and 289 ha were allocated to forest, resulting from the conversion of grassland in 2006. After the removal of the soil variables the location suitability for agriculture increased – these cells are in fact located in the flat bottom of the valley. The pixels converted to forest are caused partially by the soil variables and partially form the labour structure variables removal. In fact the pastures abandonment might lead to reforestation of some areas (e.g. Tappeiner et al. 2008) – these cells are spread out in the study area, with a big share among them located in remote areas. 1.1 % was allocated to bare land, from cells classified as bare land in 2006.

Bare land. 98.6 % of the bare land remained in the same class. Only 23 ha (1.3 %) were converted to forest and 1 ha (0.06 %) to grassland, due to random effect.

Water. 1 ha of water was allocated to forest.

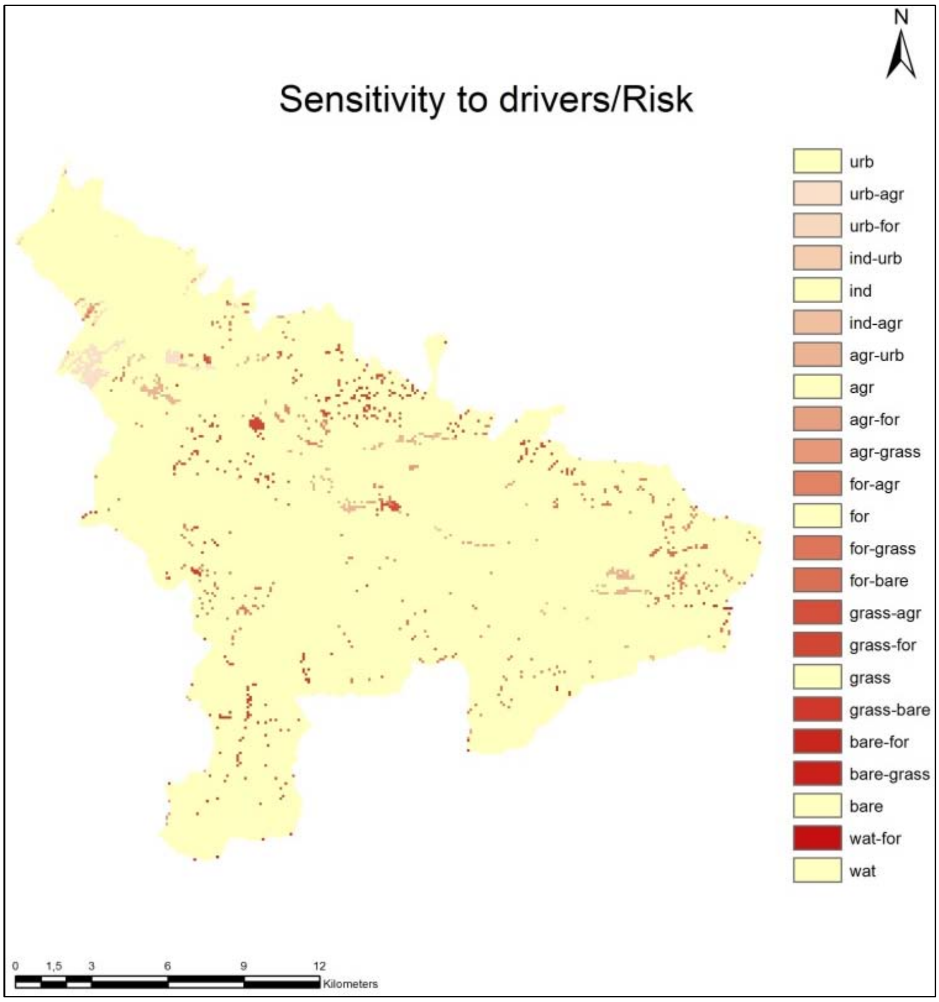

Figure 33. Map of change between the simulated map with the full set of variables and the simulated map with only nineteen drivers – overall risk scenario, no restrictions. The yellow pixels show the cells which did no experience any change; the scale of reds, shows the changes among the land use classes.

Comparing the outcomes of the two runs, turned out that the patterns of change between the two scenarios Overall Growth and Overall Risk are very similar. The locations, or hotspots, where the changes caused by the different set of variables are happening, are pretty much the same. The differences are due to the scenario trends which push certain classes to develop: the differences involve mostly the urban and industrial classes. Generally the pixels presenting differences between the "30 drivers" and the "19 drivers" runs come either from the same class in 2006 (non-conversion), or from a conversion which followed different dynamics. The majorities though are pixel coming from the same class in 2006 (non-conversions). In the overall growth simulation, being the urbanization/industrialization push stronger, the allocation of these two classes is more frequent compared to the overall risk scenario. For example, in the growth scenario in four cases not-urban/industrial classes are allocated into urban/industrial – 524 ha of agriculture, 20 ha of forest, 92 ha of grassland – while in the risk scenario only 181 ha of agriculture are allocated to urban. Lacking certain rules given by the labour structure and soil variables, in the scenario led by strong urbanization/industrialization, big portion of surface are easily occupied by these two classes. Thus, when the removed variables do not support the "weakest" classes anymore – e.g. agriculture supported by soil and by the presence of many farms – they are even more easily eaten by "stronger" classes supported by higher elasticity values and by the scenario trends.

Nevertheless, a share of the observed differences is due surely to a random effect not simply explainable by the different set of driving factors. Thus, random dynamics still have a part in the land use modelling simulation (Verburg et al., 2013).

6 Conclusions

An area composed by eighteen municipalities in the Ill-Walgau in the Austrian federal state of Vorarlberg. The region includes 18 municipalities and two relatively big cities, Feldkirch and Bludenz. The choice is due to the interesting spatial arrangement of the area which alternate a well-developed infrastructure network, a high percentage in forest cover, industrial areas. As we observed, the past two decades didn't face substantial landuse change – in comparison with the decades from the 50's to the 90's – hence we may also expect that the next three decades will follow the same trend of the recent past. Still, the spatial planning is or should be one fundamental pillar of risk management, although is not yet a homogenous and standardized element in risk management in Austria (Holub & Fuchs, 2009). In order to test the dependencies between natural hazard exposure and spatial planning, we used the land use change model Dyna-CLUE (Verburg et al. 2002).

This analysis was carried out in order to test the potential and limitations of the model Dyna-CLUE in the Ill-Walgau. The model generally behaved well, since the difficulties of simulating the complexity of the bio-physical and socio-economic relations in a mountain environment have to be acknowledged. The simulation in such a terrain poses surely more challenges than simulations carried out on morphologically more simple terrains. The potential shift in the exposure if no spatial restriction policies are implemented was observed: with no restrictions applied, the output difference between the scenarios is significant. Therefore, if no constraints are implemented during the spatial planning process, the outcome is led by the scenarios, which are very often not under the control of the local authorities. The exposure in fact raises considerably on the *Overall Growth* scenario.

The response to spatial policies and restrictions was generally good. Nevertheless, a small part of the restricted cells have been allocated to a different land use class. In other words, in the areas where the restrictions are applied no change in the pixel distribution should be observed, as with the restrictions those pixel are simply told to not to change. Although as already mentioned, the restriction configurations did have a significant effect on the simulated outcomes, it was not completely hermetic, since a small number of pixels in the restricted areas have been converted. The explanation that could be given is the following. The model has several elements defining how to perform the land allocation: the matrix, the restrictions, the driving factors and the scenarios (Verburg et al., 2002). Somehow in certain cases - especially with extremely restrictive policies - these elements get into contradiction between each other. The model must allocate the land according to the defined rules: with large restricted surface and the remaining land being not suitable for certain land use classes, we observed a few pixels escaping the restrictive policies. These pixels are located always in flat areas at the valley bottom, where the interference between driving forces and restrictions is stronger. According to the results of the logistic regression, the suitable area for urbanization and industry is the flat valley bottom, where also a big part of the restricted floodable areas is located. The quantification of the change in the land use as given by the scenario must be met by the model, thus a part of the restricted pixels are forcedly converted despite the restrictions.

Plausibility of the conversions are in line with the literature (Cammerer et al. 2013; Price et al. 2015; Zheng et al. 2012) and coherent with the bio-physical and legal environments. Generally no unattainable conversion took place in the simulation phase; for instance no forest was converted to urban, or no industrial area was changed into grassland. This fact is very important in order to add a new validation example for the Dyna-CLUE, at least regarding the specific transition settings (matrix and elasticities).

As already stated also Price et al. (2015) the modeled scenarios are not expected to fully represent the reality, since the incorporation in the data management and simulation phases of all the factors, and their feedbacks and interactions, leading to big uncertainties in the land use change modelling process (Verburg et al. 2013). The modelling approach, in fact, misses the formalization of the weaknesses and basically what cannot be processed and analyzed by numbers and models remains often unstated (Mazzorana et al. 2009). However, underlining and stressing the presence of such a big number of uncertainties – nowadays the risk management is based on certain assumptions, like design events, hazard zonation, etc. – should lead to a more thoughtful planning phase and development.

The modelled output depends very much on the quality of the spatial database (Castella et al. 2007). In this study CORINE dataset was used. Being Dyna-CLUE a probabilistic model, we believe that a finer land classification does not necessarily improve the outcomes (e.g. Cammerer et al. 2013) with more realistically simulated land use maps. For instance, the accuracies of the "industrial" class in the simulated maps show values well below the other classes: this is due to the lower relative surface of commercial units compared to other land use classes. Thus, more land use classes with a decreased relative sample size and, as a consequence with the challenge to identify the proper drivers influencing the land pattern, may lead to a less precise land allocation (also stated by Conway 2009 and Pontius et al. 2008). The quality of the input affects heavily the quality of the outcome. The resolution can surely be further improved analyzing the past ortho-photo (e.g. Cammerer et al. 2013) in order to integrate the available land use datasets, which are often lacking. Nevertheless, with very small grids the subdivision of the study are into sectors is advisable in order to partially avoid the sample size and drivers identification problems, above mentioned. Another input quality issue encountered in the calibration phase, has to do with the classification methods and technologies adopted by the CORINE group across the years. The classification in 2012 was improved, leading to appreciable differences form the 2006 map, that affect the calibration of the model. In fact, in the industrial surfaces, some discrepancies between the two years were noticed.

Observing the past land use development either through visual comparison of the ortho-photos or through the literature, it is clear that the strong development wave across the alpine valleys already happened in the last half century (50s-90s) (Fuchs & Bründl 2005). The big transition of many alpine communities from the rural traditional society towards a tourism- and service-oriented society (Fuchs & Keiler 2008; Promper et al. 2014) took place in the past decades, thus it is implausible that these communities will undergo in the next thirty years significant land use changes. Nevertheless, in many cases the past spatial planning and political choices are still influencing the future development (e.g. Glavovic et al. 2010). Therefore the implementation of effective spatial-planning tools, with legally binding nature, is still needed in the context of risk management. At the actual state, in Austria only in the red zones a building ban is present, although it can be circumvent (Holub & Fuchs 2009). The red zone are the Red zones from the WLV and part of the HQ30 by the BMLFUW are classified as red zones; therefore more than ca. 1200 ha are classified as yellow zones, based on the design event concept – 150 years for the WLV zones and 30 and 100 years for the BMLFUW. This means that the uncertainties are considerable, since the design event concept might not fully reflect the future conditions (e.g. flood in 2005, Land Vorarlberg (2015)), which might change due to climate modifications (e.g. Allamano et al., 2009; Bouwer et al., 2010; Mazzorana et al., 2012; Staffler et al., 2008).

Observing the results from an absolute-number perspective, the conclusion that might be drawn is that the proportion of exposed pixels is really low if compared to the total area. It has though to be taken in mind that one pixel corresponds to one hectare. The surface of one hectare might host a considerable number of assets and people – houses, industrial areas, and infrastructures. Especially regarding the infrastructures, the extent of the damages is hardly to be fully assessed. Therefore, even though the proportion of hazarded surface is relatively low, still considerable mistakes can be done in the spatial planning context, above all when big interests are involved. Moreover, looking at the Ill-Walgau considering just the area suitable for permanent settlements (Statistik Austria 2008) – which is about one third of the total – the proportions change considerably and the share of exposed surface increases. Assuming at this point, that climatic shifts and variations are happening and are about to happen with higher frequency in the European Alps, the interface zone between human sphere and natural hazard is expected to increase with the result of having higher risk. In the State of Vorarlberg only areas of particular relevance for the planning activities have to be displayed in the context of hazard mapping, being not mandatory to have a minimum level of detail (e.g. runoff zones, retention basins, etc) (Holub & Fuchs 2009) that might allow to handle crucial information. The study was undertaken analysing the shift in the exposure due to land use changes in the Ill-Walgau without considering the effects of climate change. Further research should be implemented adding this variable to the overall picture, digging deeper into the natural hazards changing patterns, including their interactions with land use change. The outcomes of land use change future scenarios should be coupled with the outcomes of the natural hazard behaviour simulations, under changing conditions. The combining of these two outcomes may allow reaching a more holistic view on the processes involved. The identification of future potential exposure-shift hotspots, under certain conditions, in order to be able to structure effective land use management tools and design the proper mitigation measures. Although spatial planning activities are surely not able to lower the existing assets at risk, they are able to have a significant impact to the future exposure by adjusting the development of those plots located in endangered areas (Holub & Fuchs 2009). Therefore, in the present context of climatic changes and past spatial policies affecting the actual plots development, there is a need to develop legally-binding and mandatory restrictive tools, at the level of the local authorities and administrations, in order to limit the future exposure increase (Holub & Fuchs 2009).

6.1 Research questions: the answers

Summarizing the goals of the study.

(1) Test the potential and limitation of the Dyna-CLUE in an alpine environment.

The difficulties in modelling the spatial complexities of the alpine environment are repeatedly stated in the literature (e.g. Mazzorana & Fuchs 2010a). The variables to be accounted in a morphologically very diverse system are many more than in a flat terrain. Nevertheless, the Dyna-CLUE generally behaved well. The land use change simulations in such a terrain pose surely more challenges than simulations carried out on morphologically more simple terrains.

(2) Gain an idea of the potential exposure when no restrictions are implemented.

The potential shift in the exposure if no spatial restriction policies (e.g. building ban in hazard zones) are implemented was observed: with no restrictions applied, the resulting spatial patterns is significantly different between the scenarios. Therefore, applying this concept to the real spatial planning process, if no restrictive policies aimed at hindering the urban sprawl in endangered areas are implemented, during the, the out coming landuse mosaics are led by the scenarios, which are very often not under the direct control of the local authorities. The exposure in fact raises considerably more in the *Overall Growth* scenario if compared with the *Overall Risk* scenario.

(3) Analyse future spatio-temporal dynamics of exposure to natural hazards until 2030, while testing the model response to different land use restriction policies.

The model response to spatial policies and restrictions was positive, in the sense that the implementation of the three different spatial restriction configurations – Light, Medium and Heavy Restriction – was detected and processed by the model with success. In the areas where the restrictions are applied no change in the pixels pattern should be observed (no pixel is allowed to be converted inside the restricted area), as with the restrictions those pixel are simply told to not to change. Nevertheless, a small part of the restricted cells have been allocated to a different land use class. Hence, the restriction configurations did have a significant effect on the simulated outcomes, but the restrictive effectiveness was not completely hermetic, since a small number of pixels in the restricted areas have been converted. The explanation that could be given is the following. The model has several elements defining how to perform the land allocation: the matrix, the restrictions, the driving factors and the scenarios (Verburg et al., 2002). Especially with extremely restrictive policies all these elements get into contradiction between each other. These pixels are located always in flat areas at the valley bottom, where the interference between driving forces and restrictions is stronger.

(*4) Test the sensitivity of the Dyna-CLUE to the number and to the quality of the driving factors.*

Two simulations were run to assess the model sensitivity to the driving factors, using the Overall Growth and Overall Risk scenarios. The outcomes showed very similar patterns of change. The locations, or hotspots, where the changes caused by the different set of variables are happening, are pretty much the same. The differences involve mostly the urban and industrial classes. Generally the pixels presenting differences between the "30 drivers" and the "19 drivers" simulations come either from the same class in 2006 (non-conversion), or from a conversion which followed different dynamics due to the different set of drivers. The majorities though are pixel coming from the same class in 2006 (non-conversions). Being the urbanization/industrialization push stronger in the overall growth simulation, the allocation of these two classes is more frequent compared to the overall risk simulation. When the location preference pattern given by the labour structure and soil variables lacks, in the scenario led by strong urbanization/industrialization, big portion of surface are easily occupied by these two classes. In other words, when the removed variables do not support in terms of preference (probability) the "weakest" classes anymore – e.g. agriculture supported by soil and by the presence of many farms – they are even more easily eaten by “stronger” classes supported by higher elasticity values and by the scenario trends. Nevertheless, a share of the observed differences is due surely to a random effect not simply explainable by the different set of driving factors. Thus, random dynamics still have a part in the land use modelling simulation (Verburg et al., 2013).

6.2 Outlook

This study was carried out excluding the effect of climate change on the hazard dynamics (e.g. frequency, magnitude, etc.). Climatic shifts are yet a reality we experience every year and in every season, especially in mountainous context like the European Alps (e.g. Allamano et al. 2009; Bouwer et al. 2010; Mazzorana et al. 2012; Staffler et al. 2008). Therefore, the interface zone between human sphere and natural hazard is expected to increase from both directions: natural hazards increasing magnitude/frequency and increasing exposure due to land use changes. Further research should be implemented taking into account both climatic variation affecting natural hazards behaviour, and land use changes causing an increase in the exposure. Land use changes are not only increasing the exposure to natural hazards (Cammerer et al. 2013; de Moel & Aerts 2011; Wheater & Evans 2009), they are also affecting the hazards propagation and behaviour (e.g. Dorren et al. 2004; Dorren et al. 2007; Chiari et al. 2010; Schwarz et al. 2010; Papathoma-Köhle & Glade 2013; Chirico et al. 2013). Thus, the future research should be focused on the interactions of these two elements which are contributing to increase the risk: the outcomes of land use change future scenarios should be coupled with the outcomes of the natural hazard behaviour simulations, under changing conditions and accounting for the above mentioned feedbacks. The identification of future potential exposure-shift hotspots might allow to structure effective land use management tools and design the proper mitigation measures.

In order to a have the most realistic and detailed picture a cross-sectoral approach could be followed, incorporating several aspects and issues which are apparently not directly linked with natural-hazard science: political events, history, migrations, economic changes, demographic development, structure of the society, etc. It is the opinion of the authors, that National and European top-down policies do not always meet the real needs of the communities. The decisions-making process is often not-linked with the territory, lacking of concreteness. The Alpine area is an incredibly complex territory which deserves specific attentions and tailored measures (Mazzorana & Fuchs 2010). In our case, we must produce a comprehensive mosaic-picture of the alpine space in order to adapt the land-use policies and regulation to the real needs of our valleys (bottom-up approach) taking into account all the factors involved. Using land-use change models as tools for integrated environmental management, through scenario analysis and scenario development we can identify future critical locations in the face of environmental change.

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APPENDIX A

Driving factors sources

In the following lines the sources and the calculation methods of the driving factors are briefly explained.

Austrian Digital Elevation Model (5m resolution)

From the DEM were derived four maps rasterized with a grid of 100 x 100 m: areal incoming solar radiation (WH/m^2), slope inclination (degrees), aspect (compass direction from 0 to 365 degrees) and elevation from the sea level (m).

Hydrologic atlas of Austria HAÖ

Geology. Form this dataset were derived one geologic map and one soil map according to the standard international classification by FAO (FAO, 1976). These two maps are derived from the European Soil map 1:1 Mio (Nestroy 1999). Both maps were rasterized with a resolution of 100 x 100 m.

Temperature (°C). From the ZAMG Karte 1.6, based on the interpolation of temperature measurements from 1961-1991, I create the annual mean temperature map which was extracted for the study area and rasterized with a grid of 100 x 100 m.

Precipitation (mm). Representation of modeling results of rainfall variation based on the measured data 1961-1990. I calculated the mean between the maximum and minimum average values during the observed time-span, and then I extracted the study area and rasterized the map with a resolution of 100m.

Austrian soil map (Oesterreichisches bodenkarte)

http://www.bodenkarte.at/

Shapefile with 1 km resolution, rasterized with 100 x 100 m grid to fit the rest of the dataset. Form this dataset were produced two maps representing one soil parameters as driving factor: soil permeability according to the FAO definitions (FAO 1976).

VoGIS geodatabase

http://vogis.cnv.at/

Political division of Vorarlberg (municipalities), transportation network, point of interests (hospitals, schools, rescue stations) from which were produced six maps expressing six different driving factors: distance from the railway station, distance from the roads, distance from the highway, distance from the schools, distance from the hospitals and distance from the main cities, which were calculated with the cost distance.

The socio-economic parameters were calculated from the database provided by the Statistik Austria (http://www.statistik.at/blickgem/gemList.do?bdl=8).

For each of the eighteen municipalities of the study area where spatialized several socio-economical parameters.

Population parameters

Population density (inhabitants/km^2). Although the population data were updated until 2015, I chose the data from the 2011 (the second up-to-date year) because the values of the others parameters have been measured in 2011 and 2012 – anyway the population does not show a big increment between 2011 and 2015.

Housing

Private household was calculated as a percentage from the total house tenure structure of each municipality.

One-, two-, three-, four-, multi-persons private households was calculate as a percentage of the total private households for each municipality.

Labor structure

Activity rate is measured as the percentage of the number of people which have the requisites to be employed (including the unemployed subjects) from the total population of each municipality.

Labor force is calculated as the percentage of the number of people which are currently employed from the total population of each municipality.

Unemployment rate is calculated as a percentage of unemployed subject from the total population of each municipality.

Economic sectors

The data concerning the job typologies provided by Statistik Austria were summed up in the three canonical sectors: primary, secondary and tertiary. Hence according to the definition given by Kenessey in The primary, secondary, tertiary and quaternary sectors of the economy (1987) the primary sector is composed by agriculture, forestry, mining activity, energy supply, water supply and waste management; the second sector counts production of goods and construction industry; the third one comprehends commercial activities, transportation, gastronomy and accommodation, information and communication, finance, property and housing, technicians, administration, education, health and art.

So according to this categorization of the economic activities I calculated, based on the data provided by Statistik Austria, the employees and the enterprises rate in the first, second and third sectors. Employees in the primary, second, third sectors is a rate between the total labor force of each municipality and the number of employees in each sector. The enterprises rate is calculated as a percentage of the total enterprises and the enterprises operating in each sector per each municipality.

Commuters

For each community was spatialized the data regarding the number of people which work outside the municipality where he/she lives. This rough data could be better represented adding the specification of the destination of the worker, ending with a complicate flux maps which for the purpose of landuse modeling cannot be accounted by the model.

APPENDIX B

Main file

Line	*Title*	*Description*	*Format*
1	Number of land use classes	Max. 12 categories	*Integer*
2	Number of regions	Default = 1; max 3 regions	*Integer*
3	Max. nu number of driving factors in a regression equation	Max. 20 variables	*Integer*
4	Total number of driving factors	Max. 30 drivers	*Integer*
5	Number of rows	Extent of the area grid	*Integer*
6	Number of columns	Extent of the area grid	*Integer*
7	Cell area	Resolution of the raster files	*Integer*
8	xll coordinates	X coordinate of the lower left corner	*Float*
9	yll coordinates	Y coordinate of the lower left corner	*Float*
10	Codes of the land use classes	From 0 to 12	*Integer*
11	Elasticities values	Each land use class have assigned one value between 0 and 1	*Float*
12	Iteration variables	Three number: unit of the convergence criteria, first convergence crit.: average deviation between demand changes and allocated land, second convergence crit.: average deviation between demand changes and allocated land	*Float*
13	Start and end year of the simulation	From the present year to the future year in the simulation	*Integer*
14	Number and code of dynamic driving factors	How many dynamic drivers there are and their codes	*Integer*
15	Input/output choice	Extensions of the output ASCII e.g. ArcGIS, Idrisi	*Integer*

16	Region specific regression choice	Same regression for all the area (0), different regressions for different regions (1), different regression with different demands (2)	*Integer*
17	Initialization of land use history	Initial land use history: each pixel can be classified with a required value that represents the number of year that that cell was occupied by the actual land use class (0), a random number is assigned to each pixel with two criteria (1 or 2)	Integer
18	Neighbourhood calculation choice	Choice for using the neighbourhood function. Default = 0	*Integer*
19	Location specific preference addition	Variables for location specific preference addition, default = 0	*Integer*
20	Optimal iteration parameter	Iteration parameter. The value of this parameter should be between 0.001 and 0.1	*Float*