D.T 3.4.1: Report on “Development of TEGRAV risk management strategies in relation to CC and SC”

GREEN
RISK
4 ALPS

WP 3

Responsibility for Deliverable

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1. Introduction

The project *GreenRisk4ALPs* aims to develop ecosystem-based approaches to support risk management of the Alpine region. In particular, the project intends to provide decision support tools for the development of ecosystem-based risk management strategies for mountain regions. Risk management strategies should be not only fitting to current conditions but also address changes in the risks expected for the future.

Risks result from the combination of natural hazards and the vulnerabilities of exposed elements; they therefore derive from the interaction between natural and social systems (Cardona et al., 2012; IPCC 2014). Natural hazards and social systems are both subject to changes leading to transformations in the temporal and spatial patterns of the resulting risks (Promper et al., 2014; Van Westen, 2010). On the one hand, climate change is influencing natural hazards frequency and intensity as well as their geographical location and extent, duration and occurrence time (IPCC 2014). On the other hand, landscape processes and society are subjects to dynamical changes: urban growth and changes in land use shape the landscape leading to a subsequent modification of the respective risks (Fuchs et al., 2013; Van Westen, 2010). Thus, increasing knowledge about one specific component, either the hazard, the elements at risk or their vulnerability without analysing the interactions among them is not sufficient to improve risk reduction strategies (Fuchs et al., 2013). Consequently, risk assessment cannot be a static procedure; it is paramount for such evaluations and for the stemming risk management decisions to analyse and consider changes in the natural and social systems (Van Westen, 2010).

In this context, this deliverable aims to provide an overview of use cases and applications on how to include climate and social change when assessing different risk management options through tools developed within the *GreenRisk4ALPs project* (TEGRAV analysis, integrated in the FAT tool). Chapter 2 focuses on the changes of the social system, by presenting an overview of social developments and approaches to analyse them in the Alpine region. Chapter 3 presents some use cases and application examples to use the FAT tool for planning under changing societal and environmental conditions.

2. Changes in the social system

The social system and therefore land use, elements at risk exposed and vulnerability are not constant over time. This leads to modifications in the spatial and temporal distribution of risks (Promper et al., 2014). Acknowledging the need to include these dynamics into the risk concept (Fuchs et al., 2013), section 2.1 aims to provide examples of current demographics and past trends in the Alpine social system. These trends should be taken into account when assessing how risk can evolve in the future. Moreover, Section 2.2 presents possible approaches to better assess future risks.

Observed and projected climatic changes in the Pilot Action Regions (PARs) and their potential effects on forest parameters and on gravitational mass movements can be found in Deliverable DT 1.1.1.

2.1. Alps demographics and past trends

Although the natural functions of mountain environments (such as biodiversity, water, energy, and biomass supply) are often highlighted, the Alpine region has always had and still has an important urban function and cannot be merely considered as rural area (Bole et al., 2016). The presence of people, infrastructure, businesses make up the urban character of the Alps; such elements could however be potentially be affected by gravity driven natural hazards, which commonly occur in mountain areas. Investigating the current and future distribution of the population and assets, helps to better pinpoint potential risks and to subsequentially choose the most appropriate risk management option.

More than 14 million people live in 190,700 km2 surface which constitutes the Alps, where more than 5000 municipalities are present (Permanent Secretariat of the Alpine Convention, 2018). Towns in the Alps are principally small and medium-sized and provide the backbone of social, economic, and cultural activities (Bole et al., 2016). With an average population density of 74.6 inhabitants per km2, the Alps can be generally considered as a rather sparsely populated area, but significant demographic differences exist among the regions (Alpine Convention, 2015). The distribution of human settlements is mainly influenced by topography. Valley floors offer more spaces for infrastructure, housing, and productive activities and thus allow for easier settlement (Permanent Secretariat of the Alpine Convention, 2018). Alpine valleys are consequently characterised by higher population density compared to the nearby steeper areas (Alpine Convention, 2015) (see Figure 1). Population density of valleys reaches similar levels to non-Alpine regions and it is comparable with the most densely populated regions in the world (Bole et al., 2016)

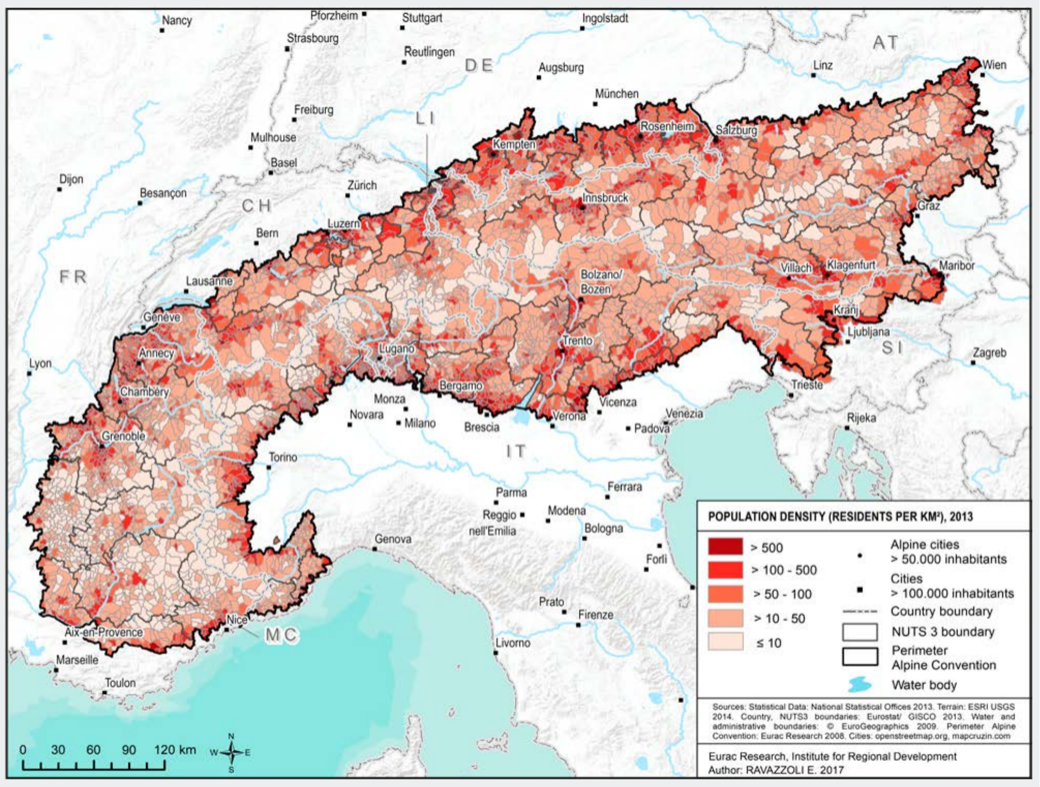
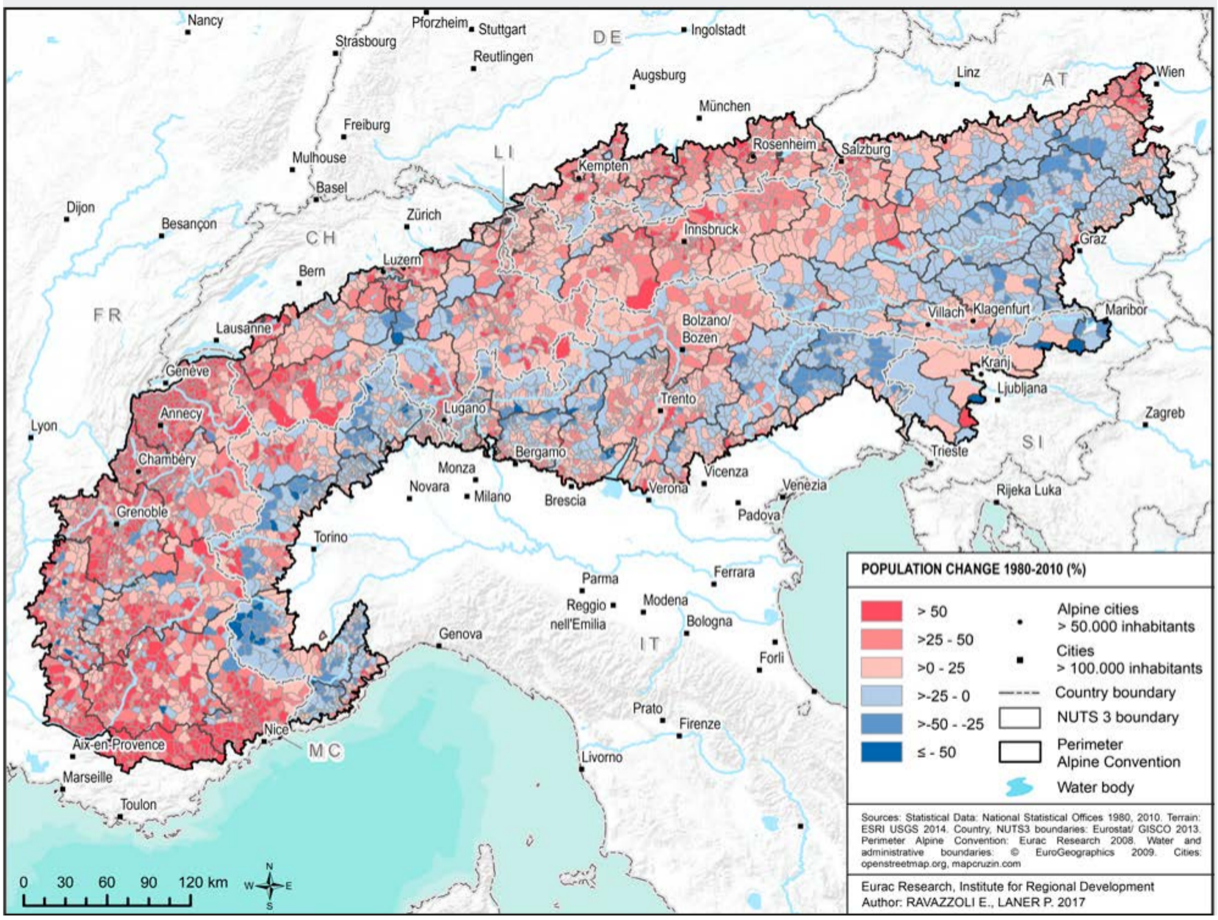


Figure 1: Population density (residents per km2), year 2013. (Source: Permanent Secretariat of the Alpine Convention, 2018)

Demographic trends are not equally spread across the Alpine region (Price et al., 2012): some areas are characterised by population loss or stagnation while others by repopulation (Alpine Convention, 2015). Generally, differences depend on factors such as accessibility, topography and altitude and on the location and socio-economic role of the Alpine region in each country. At every scale (e.g. municipality, region) it can be generalised that areas with growing populations are often adjacent to those where population is decreasing (Price et al., 2012). Overall, since the 1980s the population of the Alps has been growing and is continuing to do so (Permanent Secretariat of the Alpine Convention, 2018). For the Alps as a whole, migration contributes more to population change than natural population growth. Economic disparities between urban and rural areas and the improvement of infrastructure services have also led to rising internal migration (Price et al., 2012).

Urbanization processes in the Alps do not differ considerably from those in non-alpine Europe: population in European towns has been stagnating since the 1970s, while it has been growing within the commuter belts (Perlik et al., 2001). This phenomenon, referred to as periurbanization, also dominates the Alpine region, mainly due to the scarcity of land in the valley bottoms. Within the Alps, however, urbanization occurs with a time lag and at a smaller scale (Perlik et al., 2001).



Sources: Statistical Data: National Statistical Offices 1980, 2010. Terrain: ESRI USGS 2014. Country, NUTS3 boundaries: Eurostat/ GISCO 2013. Perimeter Alpine Convention: Eurac Research 2008. Water and administrative boundaries: © EuroGeographics 2009. Cities: openstreetmap.org, mapcruzin.com

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Author: RAVAZZOLI E., LANER P. 2017

Figure 2. Percentage of population change from 1980 to 2010 in Alpine NUTS3 regions (Source: Permanent Secretariat of the Alpine Convention, 2018)

As it can be seen in Figure 2, the most visible trend when observing the development of population at the regional Alpine scale is spatial polarisation between growing and declining areas. Western, Central and Northern municipalities of the Alps have witnessed a population increase since the 1980s. On the contrary, in the South and East of the Alps the population has increased (Permanent Secretariat of the Alpine Convention, 2018). If the population increases and urbanisation takes place in hazard prone areas, also the subsequent risk connected to the potential occurrence of natural hazards rises.

Not only the population but also other elements at-risk change continuously. Their spatial distribution is influenced by land use and land cover changes (Promper et al., 2014). Land use and land cover changes have occurred throughout Europe in the last decades, set in motion by a variety of connected processes acting at different scales (i.e. economic growth, technological or political changes, migration from rural to urban areas or vice versa) (Verburg et al., 2008). Land use and land cover do not only determine which elements are potentially exposed; it is also acknowledged that land cover changes induced by human activities strongly influence slope stability. In particular, forest cover is an important factor which influences slope stability as a result of hydrological and geo-mechanical effects (Glade, 2003; Marston, 2010).

2.2. Future developments and examples of future scenarios approaches

The previously described socio-economic developments in the human-made environment led to an asset concentration over time. Thus, the temporal variability of elements at risk is an important key variable in the assessment of risk. Previous studies have analysed the temporal variability of elements exposed to mountain hazards, with respect to both the long-term and the short-term evolution (Fuchs et al., 2005; Keiler et al., 2005). Long-term changes are connected to the increase in numbers and values of buildings threatened by natural hazard processes and can be observed in both rural and urban areas in mountain regions of Europe (Fuchs et al., 2013).

Different approaches can be used to study future developments: qualitative methods, such as stakeholder interviews or other participatory approaches (ESPON, 2018), cognitive mapping (Malek, 2015), geospatial methods such as geographic information systems, geostatistics, and environmental modelling (Promper et al., 2014). A combination of different methods is also possible: involving stakeholders at different stages to support the steps of generating data, understanding the system of land use change, and developing land use change models. Since some land use changes are highly dependent on national and local policies and individual events (i.e. large investments), for use in local decision-making, it is crucial to involve local experts to map local specificities (Malek, 2015).

One approach to address the spatio-temporal variability of risks is to analyse past land cover changes, as well as future development of the land use and land cover using scenario-based approaches (Promper et al., 2014). Scenarios can be considered as alternative images on how the future might unfold (Promper et al., 2014). Scenarios have emerged as useful tools to explore possible future developments in complex ecological and anthropogenic systems that typically have high levels of scientific uncertainty (Alcamo et al., 2008). They differ from predictions, forecasts and projections in that they describe alternative futures under different sets of assumptions based on territorial evidence and ex-post analyses of long-term past developments and their connected drivers (ESPON, 2018).

Scenario analysis is the procedure by which scenarios are developed, compared, and evaluated (Alcamo et al., 2008). This procedure does not eliminate the uncertainties about the future, but it allows to represent current knowledge in the form of consistent, conditional statements (Alcamo et al., 2008). The further in the future scenarios are, the larger becomes the uncertainty. This is particularly true for future territorial development as they are influenced by a multitude of causes, complexly interrelated between each other (ESPON, 2018).

To develop future scenarios, regional and local analyses of past, current and future socio-economic trends and driving forces should be carried out (Hersperger et al., 2018). The main driving forces of spatial development to account for in the Alpine region are political and societal decisions, economic dynamics, and the environmental context (ESPON, 2018). As for other approaches, scenarios are best developed not by researchers alone but with stakeholder participation, allowing different experts to discuss, negotiate and reach agreement (ESPON, 2018; Malek, 2015). Usually participatory scenario development does not generate (detailed) spatially explicit results.

For instance, the Alps2050 project, developed a set of scenarios for the Alpine region with the use of the Delphi method, a participatory approach, taking into account the analysis of past trends (ESPON, 2018). They identified one status quo scenario that foresees the continuation existing patterns and trends, and three contrasting scenarios that reflect the differences in priorities and political world view. In particular, Alps2050 looked at the future developments of specific themes such as the economy, the environment and the demographics, proving both textual descriptions and visual sketches. These however are very condensed and simplified (Figure 3). Thus, they are not intended to be spatial planning concepts but visions that present the range of opposing priorities and their implications.

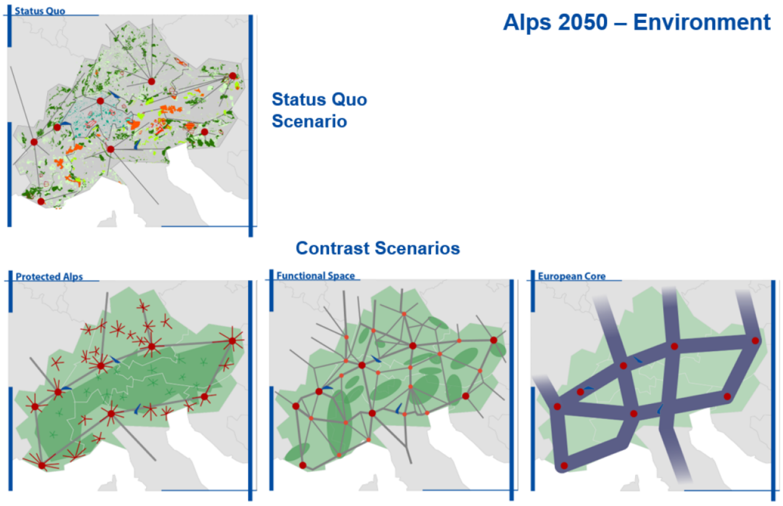

Figure 3. Different scenarios for the alpine environment developed by the Alps2050 project (Source: ESPON, 2018)

The previously described scenarios designate possible futures at regional or Alpine scale. Gravitational natural hazards however are a punctual/local phenomenon occurring at the slope scale. In the context of risk assessment and management, spatially explicit modelling is needed to identify critical areas that are likely to undergo change. In such cases, the participatory scenario development process could be been combined with spatial simulations (Malek, 2015; Swetnam et al., 2011; van Berkel and Verburg, 2012).

In the *GreenRisk4ALPs* context, the Forest Assessment Tool (FAT) utilisation can be adapted (see following chapter) in order to assess how local changes in the social system (i.e. urban expansion on a selected slope) may influence the costs and benefits of different risk management measures. In future applications, the FAT could be combined with participatory processes to pinpoint hotspots which could be prone to urban expansion or forest change.

3. Use cases of FAT under CC and SC and applications

Rigorous land-use planning based on hazard zone maps and appropriate risk mitigation measures are crucial parts of risk management strategies for authorities and stakeholders in mountain risk-prone areas. However, the design and optimisation of both structural and non-structural protective measures require precise risk analysis and evaluation, also accounting for environmental and societal developments over time (Farvacque et al., 2019). In this context, the Forest Assessment Toolbox (FAT) can help stakeholders and practitioners to make an informed choice on the costs and benefits of different structural, green and avoidance measures, taking also into consideration future social and environmental changes.

After a brief presentation of the tool, this chapter presents its potential use cases and application examples.

3.1 Potential uses of FAT under CC and SC

FAT is a tool, created within the Interreg Alpine Space project - *GreenRisk4ALPs*. The tool offers a user-tailored support for practitioners in forest assessment and ecosystem-based risk management. Its goal is to estimate the value of protection forest against different natural hazards (avalanches, rockfall, soil slides).
The calculation routine of the tool has two main parts:

- The first part of the tool models the chosen hazard and the effect a forest has on a hazard process in terms of energy reduction (reduction of velocity and runout distances).
- The second part the FAT tool compares different protection measures, among which the forest is considered, from an economic point of view, presenting the user with a cost/benefit analysis of different possible measures.

Further information about the tool can be found in the following deliverables: T 1.6, T 3.3.1, T 3.3.2.

One of the limitations of the tool is that it only estimates the best risk management option at the current moment, with specific inputs that the user has to provide for the model computation. Among these inputs, we find the features of the forest and the characteristics of the assets at risk. The model itself does not develop future scenarios in terms of both climate change and societal change. However, it is flexible in terms of its inputs and allows to account for different scenarios. In practice, this can be realized by changing the model inputs according to expected developments or hypothetical scenarios (e.g. deforestation, afforestation, changes in the location or value of elements at risk etc.).
Climate change scenarios, for example, can be addressed by changing the forest features input: if the climate change scenario predicts a rising in the tree line, the forest length along the profile can be changed in the online tool. At the same time if the scenario predicts, for example, an increase of insects' outbreaks, in the model it can be showed by decreasing the forest index: that is a value that ranges from 0 to 1, where 1 is the best forest structure in terms of hazard protection.
The user, however, cannot change the hazard features modelled in the tool to account for changes due to climate change.

The same system can be used to account for **societal changes**: the user can create different scenarios and obtain different outputs by changing the assets input. The tool user can add further assets or change the position of the existing ones.

These scenarios will result in different outputs deriving from the tool. The user can compare these outputs and select the better risk management option in the light of future climate and societal changes.

3.2 Application examples

The profile used for this example is situated in an avalanche prone area. The length of the profile is of approximately 2000 m and has a height of 1000 m (reaching 2350 m in its highest point). On the slopes there is a coniferous forest (mostly *Larix decidua* Mill. and *Pinus uncinata* L.) that goes from 2200 m to 1600 m of elevation.

The only asset at risk is a secondary road placed at 1500 m of elevation on the slope. (The profile features are represented in Figure 4.)

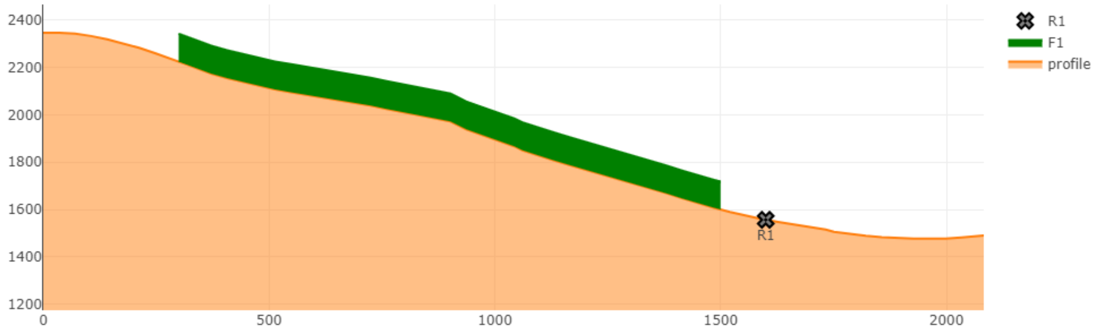

Figure 4 Features of the profile used for the example. R1 represents the secondary road and F1, in green, the coniferous forest

In this test area, we applied the scenarios explained in the previous paragraph considering both climate change and societal future scenarios.

The protection measures considered are a deviation dam placed before the road and road closure as an avoidance measure.

In the **current situation**, inputting in the model the parameters listed before, we obtain the following results:

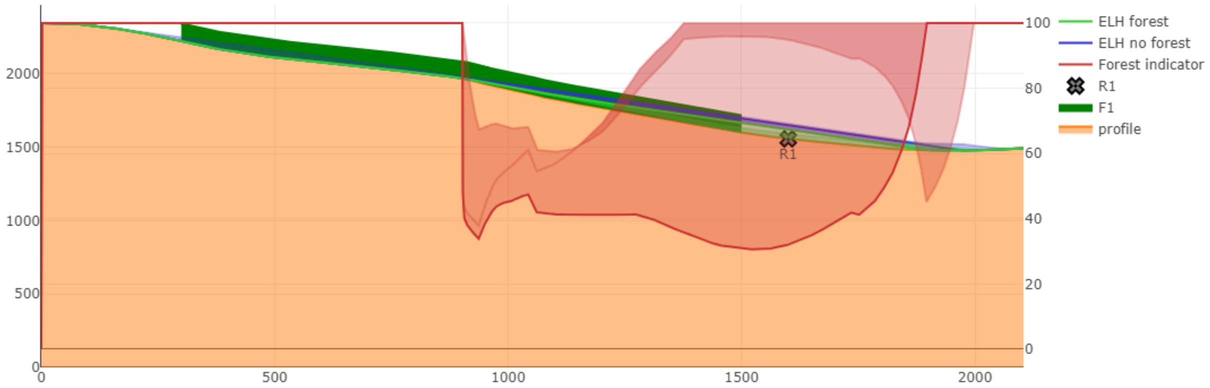

Figure 5 Graphic layout of the model result. In red the effect of the forest is represented and we can clearly see where it is more effective along the profile

Measure	Direct costs (€)	Indirect costs (€)	Avoided damages (€)	Benefits (€)
Catching Dam w/o forest	5 000 000	/	30 000 000	30 000 000
Catching Dam w/ forest	3 000 000	/	30 000 000	30 000 000
Road Closure	/	100 000	30 000 000	29 900 000

Table 1 Economic results of the tool: four different parameters are calculated for each measure

The most interesting result is the difference of the dam's direct cost with and without forest (Table 1): in this case the forest is effective in reducing the energy of the avalanche, this allows for a smaller dam. The indirect cost of the road closure measure is due to the detour that the road user has to take to reach the same destination avoiding the closed tract of the road.

To account for climate change (CC) we tested two scenarios: in the first one we hypothesized a rising of the tree line at higher elevations, while in the second one we simulated an increase of abiotic disturbances (e.g. forest fires or windthrows) due to CC.

In the first alternative scenario (Figure 6), we have increased the length of the forest until it starts almost in the detachment area. However, as we have seen in Figure 5, once the avalanche is released, the avalanche has no effect in the upper part of the profile, where the energy of the forest is higher. The economic results of this scenario are therefore equal to the previous ones (Table 2).

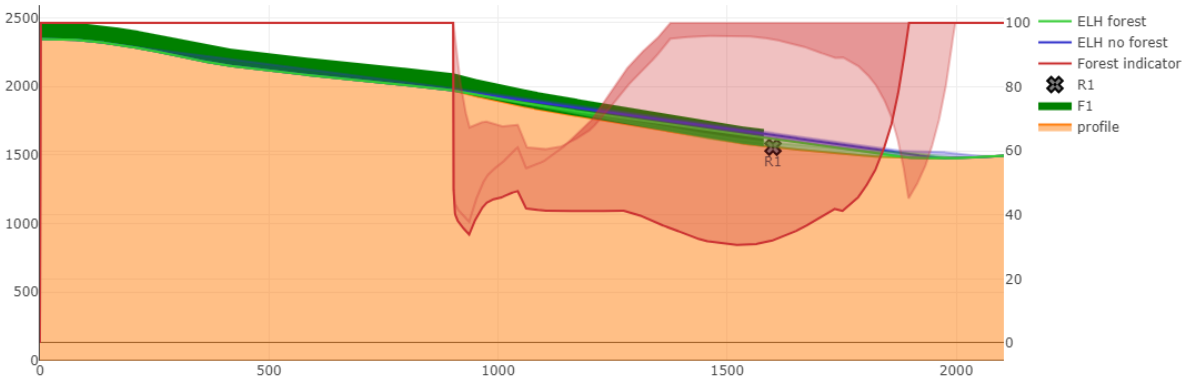

Figure 6 graphic representation of the model results for the first Climate Change (CC) scenario: the forest starts at a higher elevation compared to the first one.

Measure	Direct cost (€)	Indirect cost (€)	Avoided damages (€)	Benefits (€)
Catching Dam w/o forest	5 000 000	/	30 000 000	30 000 000
Catching Dam w/ forest	3 000 000	/	30 000 000	30 000 000

Road Closure	/	100 000	30 000 000	29 900 000

Table 2 Economic results of the first CC scenario: the forest in the upper part of the profile has no effect against the avalanche, therefore the results are equal to the ones of the actual scenario

In the second CC scenario (Figure 7) we hypothesized a large-scale disturbance (it can be either windthrow or forest fire) with salvage logging as a post disturbance management option. To simulate it we modified the forest parameter creating a large gap in the forested area.
In this case we can see a clear difference compared to the actual scenario: by removing the forest in the central part, the avalanche is allowed to run without obstacles along the slope.

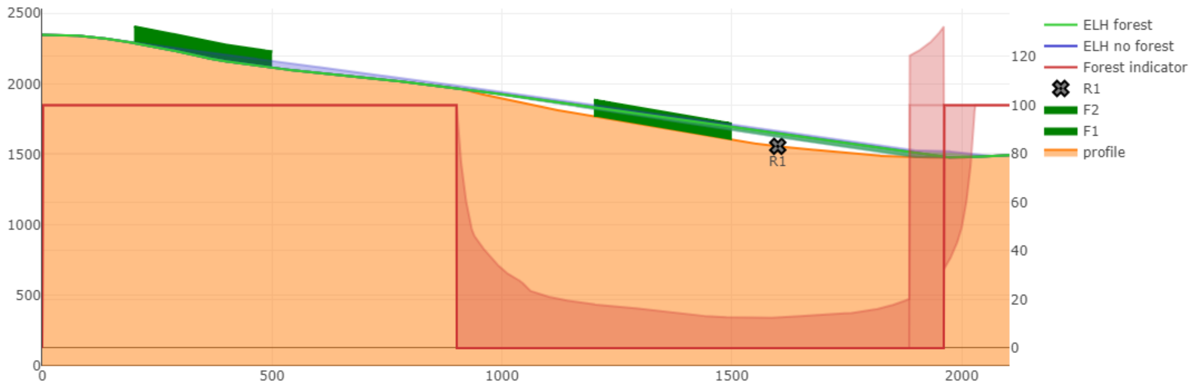

Figure 7 Graphic representation of the model results for the second CC scenario: the gap in the forest allows the avalanche to gain energy.

Measure	Direct cost (€)	Indirect cost (€)	Avoided damages (€)	Benefits (€)
Catching Dam w/o forest	5 000 000	/	30 000 000	30 000 000
Catching Dam w/ forest	5 000 000	/	30 000 000	30 000 000
Road Closure	/	100 000	30 000 000	29 900 000

Table 3 Economic results of the second CC scenario: the large gap in the forest allows the avalanche to gain energy, the ELH (the Energy Line Height parameter consists of the distance between the ground and the line connecting the top of the hazard path to the furthest run-out point of the path) before the infrastructure at risk is equal with and without forest and therefore there is no difference in the costs of the dams

In all the cases above the preferred option would be the road closure: while the benefits of these options are similar, the road closure entails a lower cost (Table 3).

Finally, to account for societal changes (SC) we added infrastructures in the runout area of the avalanche, simulating an increase in the area urbanization (Figure 8).

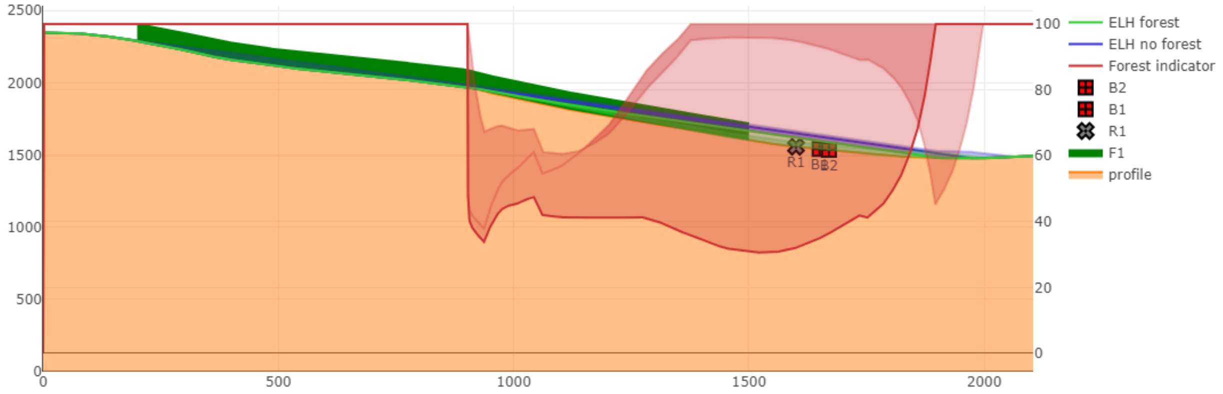

Figure 8 Graphic representation of the model results for the Societal Change (SC) scenario. Two residential buildings (B1 and B2) have been added along the profile. The hazard and slope features however, have been left unchanged and the hazard dynamic is equal to the one of the actual situation

Measure	Direct cost (€)	Indirect cost (€)	Avoided damages (€)	Benefits (€)
Catching Dam w/o forest	5 000 000	/	100 000 000	100 000 000
Catching Dam w/ forest	3 000 000	/	100 000 000	100 000 000
Road Closure	/	100 000	30 000 000	29 900 000

Table 4 Economic results of the SC scenario. Due to the higher value of the assets at risk we have different values of avoided damages and benefits

In Table 4 we can see the results of the economic model for the SC scenario. It is interesting going to analyze the values of the avoided damages. The avoided damages for the dams are way higher than the ones of the previous scenarios, that is because in this case also the value of the houses is included in the calculation. In the case of the road closure, however, we do not have a difference because by closing the road we protect only its viability, however the infrastructures near it still get hit by the avalanche. In this scenario the preferred option would therefore be the dam.

4. References

Alcamo, J., Kok, K., Busch, G., Priess, J., 2008. Chapter Four Searching for the Future of Land: Scenarios from the Local to Global Scale. Dev. Integr. Environ. Assess. https://doi.org/10.1016/S1574-101X(08)00404-3

Alpine Convention, 2015. Demographic changes in The Alps.

Bole, D., Nared, J., Zorn, M., 2016. Small Urban Centers in the Alps and Their Development Issues, in: Zhelezov, G. (Ed.), Sustainable Development in Mountain Regions: Southeastern Europe. Springer International Publishing, Cham, pp. 265–279. https://doi.org/10.1007/978-3-319-20110-8_18

Cardona, O.D., van Aalst, M.K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R.S., 2012. Determinants of Risk: Exposure and Vulnerability, in: Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M., Midgley, P.. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Cambridge University Press, UK; New York, NY, USA, pp. 65-108.

ESPON, 2018. Alps2050 - Common spatial perspectives for the Alpine area. Towards a common vision - Final Report. Luxembourg.

Farvacque, M., Lopez-Saez, J., Corona, C., Toe, D., Bourrier, F., Eckert, N., 2019. How is rockfall risk impacted by land-use and land-cover changes? Insights from the French Alps. Glob. Planet. Change 174, 138–152. https://doi.org/10.1016/j.gloplacha.2019.01.009

Fuchs, S., Keiler, M., Sokratov, S., Shnyparkov, A., 2013. Spatiotemporal dynamics: The need for an innovative approach in mountain hazard risk management. Nat. Hazards 68, 1217–1241. https://doi.org/10.1007/s11069-012-0508-7

Fuchs, S., Keiler, M., Zischg, A., Bründl, M., 2005. The long-term development of avalanche risk in settlements considering the temporal variability of damage potential. Nat. Hazards Earth Syst. Sci. 5, 893–901. https://doi.org/10.5194/nhess-5-893-2005

Glade, T., 2003. Landslide occurrence as a response to land use change: A review of evidence from New Zealand, in: Catena. pp. 297–314. https://doi.org/10.1016/S0341-8162(02)00170-4

Hersperger, A.M., Oliveira, E., Pagliarin, S., Palka, G., Verburg, P., Bolliger, J., Grădinaru, S., 2018. Urban land-use change: The role of strategic spatial planning. Glob. Environ. Chang. 51, 32–42. https://doi.org/10.1016/j.gloenvcha.2018.05.001

Intergovernmental Panel on Climate Change (IPCC), 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK; New York, NY, USA.

Keiler, M., Zischg, A., Fuchs, S., Hama, M., Stötter, J., 2005. Avalanche related damage potential - changes of persons and mobile values since the mid-twentieth century, case study Galtür. Nat. Hazards Earth Syst. Sci. 5, 49–58. https://doi.org/10.5194/nhess-5-49-2005

Malek, A., 2015. Participatory Scenario Development to Address Potential Impacts of Land Use Change : An Example from the Italian Alps Participatory Scenario Development to Address Potential Impacts of Land Use Change : An Example from the Italian Alps. Mt. Res. Dev. 35, 126–138.

Marston, R.A., 2010. Geomorphology and vegetation on hillslopes: Interactions, dependencies, and feedback loops. Geomorphology 116, 206–217. https://doi.org/10.1016/j.geomorph.2009.09.028

Perlik, M., Messerli, P., Bätzing, W., 2001. Towns in the Alps. Mt. Res. Dev. 21, 243–252. https://doi.org/10.1659/0276-4741(2001)021[0243:tita]2.0.co;2

Permanent Secretariat of the Alpine Convention, 2018. The Alps in 25 Maps, Book:

Price, M.F., Borowski, D., Macleod, C., Rudaz, G., Debarbieux, B., 2012. Sustainable Mountain Development in Europe.

Promper, C., Puissant, A., Malet, J.P., Glade, T., 2014. Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios. Appl. Geogr. 53, 11–19. https://doi.org/10.1016/j.apgeog.2014.05.020

Swetnam, R.D., Fisher, B., Mbilinyi, B.P., Munishi, P.K.T., Willcock, S., Ricketts, T., Mwakalila, S., Balmford, A., Burgess, N.D., Marshall, A.R., Lewis, S.L., 2011. Mapping socio-economic scenarios of land cover change: A GIS method to enable ecosystem service modelling. J. Environ. Manage. 92, 563–574. https://doi.org/10.1016/j.jenvman.2010.09.007

van Berkel, D.B., Verburg, P.H., 2012. Combining exploratory scenarios and participatory backcasting: Using an agent-based model in participatory policy design for a multi-functional landscape. Landsc. Ecol. 27, 641–658. https://doi.org/10.1007/s10980-012-9730-7

Van Westen, C.J., 2010. GIS for the assessment of risk from geomorphological hazards. Geomorphol. Hazards Disaster Prev. 205–220. https://doi.org/10.1017/CBO9780511807527.017

Verburg, P.H., Eickhout, B., Meijl, H. Van, 2008. A multi-scale, multi-model approach for analyzing the future dynamics of European land use. Ann. Reg. Sci. 1, 57–77. https://doi.org/10.1007/s00168-007-0136-4