A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT)

GREEN
RISK
4 ALPS

WP T1

Responsibility for Deliverable

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Table of contents

Table of Figures

Table of Tables

1. INTRODUCTION

In the last decades, the need for sustainable protection of people and property from negative impacts of natural hazards (avalanches, rockfalls, soil slope failures, torrential floods) has become greater as human activity is becoming widespread in Alpine Space. One of the best examples of ecosystem-based disaster risk reduction (*Eco-DRR*, also nature-based solutions) in mountainous areas are forests that either reduce onset probability of gravitational processes or provide mitigation effect and consequently reduce propagation probability and intensity of natural hazards. Therefore, forests with protective effect are increasingly being integrated into quantitative risk assessment (QRA) through different methods and models for assessing forest protective effects against natural hazards (Moos et al., 2018). For the protective effect that forest has against different natural hazards in the Alpine Space please see *Deliverable D.T1.3.2. – Assessment of forest protective effect and function for natural hazard process*, available on the GreenRisk4ALPs project (GR4A) website (https://www.alpine-space.eu/projects/greenrisk4alps/en/home). With this purpose, GR4A project has developed tool called FAT (*Forest Assessment Tool*), which offers a user-tailored support for practitioners in forest assessment and ecosystem-based risk management. Its overarching goal is to estimate the value of protective forest against different natural hazards. FAT was designed to be used by different target groups, e.g. local/regional decision makers, forest managers, safety and infrastructure managers, planning officers, local/regional public authorities etc.

FAT has two main functions. First, it estimates the effect a forest has on the hazard process in terms of energy reduction (reduction of velocity and runout distances) dependent on the “actual” forest structure. Second, FAT compares the protective effect of the forest to alternative (green, gray and avoidance) mitigation measures, to assess the economic benefit of the forest based on the replacement cost method. The FAT’s interactive web platform connects the model chain with a user friendly and organized method to load the input data, select different options and display the model chains results.

The FAT model is freely available through the web interface which has been developed by the IT company GeoCodis (https://www.geocodis.com/). Web interface enables users to input data, run the model and view the results. The web interface has been developed to be easy to use. Most of the user’s inputs are predefined via dropdown menus, and graphical results are apparent and user-friendly. Furthermore there are instructions to guide the user along the modeling process as needed via the help buttons on each page. The web interface has an option to export the necessary input data to a text file so users can run the model at another time.

The model chain utilizes many of the tools/research done for the GR4A project. A summary of the GR4A tools used in FAT are listed below:

- **CC-PROF tool:** Runout calculation of hazards based on given climate change scenarios and their effect on forest structure;
- **HazardforNET tool:** Runout calculation for the hazard processes avalanche, rockfall, debris slide;
- **PROTFOR NET tool:** Runout calculation by including forest (protective) effects for all 3 processes;
- **TEGRAV tool:** Risk assessment and cost/benefit analysis by integrating costs and protective effects of the mitigation measures (technical, ecosystem-based and avoidance) and damage potentials.

In the following sub-chapers different models that make up the FAT modelling chain and the general framework of the model will be summarized. Further information can be found in the deliverables: CC-PROF tool, HazardforNET tool, PROTFORNET tool and the TEGRAV tool. The deliverables are available of GR4A website: https://www.alpine-space.eu/projects/greenrisk4alps/en/home

2. INPUT DATA

To keep the FAT consistent with the philosophy used by Flow-Py and other GR4A models, input data need to be simple and flexible with regards to data quantity. Simple and flexible data allow for the model to be applied to the widest set of users.

The primary input data are: a) a profile of a mountain or hill slope, b) information of the forests structures, and c) infrastructure information. Lastly there are some model options and supplemental data fields that must be fulfilled depending on the chosen options. Where applicable default values have been provided for users who lack the supplemental information. Digital switch buttons are used for choosing which alternative mitigation measures should be considered for the economic replacement cost method. Some of the alternative mitigation measures require more information for the user such as the location of the protection measure (e.g. avalanche dam, rockfall net, afforestation), the size of protection measures, or where are hazards starting zones (e.g. snow fences) or paths (e.g. rockfall net, avalanche stopping dam).

More details about the primary data fields and the way it is loaded into the web platform are described in the subsections below.

2.1. Terrain data

The hill or mountain slope can be entered in two ways. The first way is loading a text (.txt) file that has a two-column structure (distance [m], elevation [m]). The second way is drawing the hazards flow path on an embedded map which gets transformed to the 2-dimensional profile path. Once the path is converted from the map, a profile data file can be saved as a .txt file for later use.

2.2. Forest data

There are many different potential users and uses for the FAT. Some user groups will focus more on field observations while other user groups will be more accustom to GIS based studies. Therefore, the input data about forest must be flexible to support the different users and uses. We developed a simple index that is easy to use for the most basic forest information but can also accommodate more detailed forest data. The Forest Structure Index (FSI) summarizes the structure of the forest with regards to the particular hazard.

FAT adopted the FSI which has also been used in the Flow-Py forest plugin (see deliverable DT3.2.1). FSI is used as an indicator for forests ability to dampen gravitational mass movements. The benefit for FSI is the range of data quality and quantity that can be used to calculate it.

The FSI ranges between 0 and 1, where 1 is the best forest with respect to natural hazard protection, and 0 is a non-forested area. It should be noted that the best forest for natural hazard protection may be hazard specific that means that a highly effective protective forest for avalanches might not perform well with regards to rockfall protection. Default values are given for each forest type if the user is unsure about the forest structure.

2.3. Infrastructure data

Infrastructure is manually input by the users. All infrastructure will need to have a user defined location along the profile and the type of infrastructure. Infrastructure types can be broken down into two classifications: buildings and linear infrastructure. Buildings are further broken down into non-residential, residential, commercial and public. Linear infrastructure is further broken down into forest roads, secondary roads, primary roads, highways, railways and power transmission lines. Some additional information will be needed depending on the infrastructure type such as building size [m²], number of people living/utilizing, and linear infrastructure will need information about traffic intensity [unitless 1-5] and detour distance [km].

3. HAZARD MODELS

In GR4A, we chose to apply the simple empirical-based hazard model in FAT instead of a more sophisticated and data demanding process-based physical models, because:

- There is a need for model flexibility in terms of input data quantity, information depth and resolution, and because the input data is supplied by many different user groups and data availability differs between countries, states and institutions.
- Empirical models are generally less computationally expensive and can therefore be applied quickly in embedded web applications.
- The empirical approach for runout models requires fewer parameterizations when compared to process-based physical models. Therefore, parameterization of FAT is relatively simple and outputs are better comparable between modelling regions.

3.1. Runout angle (alpha)

The hazard model adopted a runout angle criterion to limit how far the mass (snow, rock or earth) travels. The runout angle (α) (Heim, 1932) predicts where a gravitational hazard will stop using statistical methods based on measurements from past hazard events. It was found that the angle formed from horizontal from the top of the release area to the furthest runout area gave a statistically relevant variable that could be used to predict the maximum runouts on other slopes in the region. This angle is referred to as the runout angle or the α-angle (shown in Figure 1).

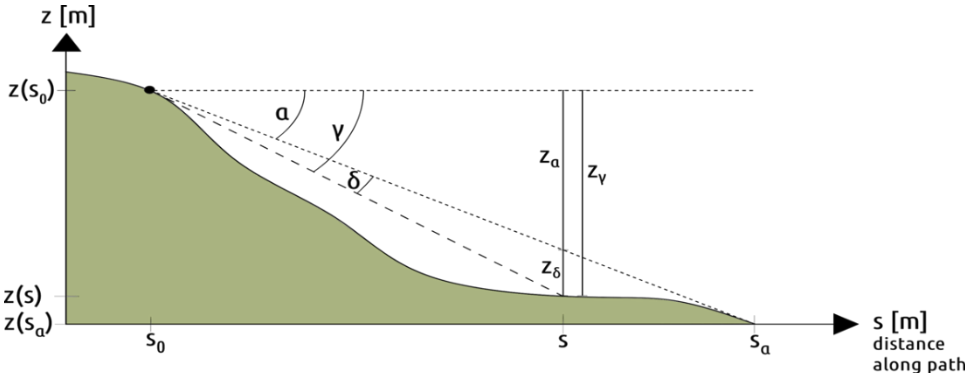

Figure 1. On the figure we can observe the runout angle (α), the local travel angel (γ), and the δ angle that is the difference between the local travel angel and the α angle.

Simplicity is one advantage of the runout angle model. The runout criterion is highly dependent on the local topography. Hence, the mathematics are the same for the different hazards (rockfall, avalanche and soil slides), however, the parameterization differs between the hazards.

For the GR4A project we try to be consistent with the methods and models that we apply. The runout angle criterion is one of the two stopping criteria that the Flow-Py model has used (more on the Flow-Py model in deliverable DT1.2.3). Therefore, the FAT tool can complement the Flow-Py results in the Pilot Action Regions (PARs).

3.2. Forest influence

There are two types of protective effects that forest exhibits in the hazard model: a) the effect of forest in the path of the hazard, and b) the effect of forest in the release areas. The forest effect in the path applies to rockfall and avalanches where release area forest effect applies to avalanches and soil slides.

The minimum data requirement for including forest in the process model is the location of the forest along the profile and the predominate forest type. If the user has more information about the forest structure the FSI can be adjusted from default values accordingly. The location of the forest with regards to the energy of the hazard along the profile is the dominant variable for energy reduction. The forest type and FSI are less sensitive parameters and have less influence over reducing the hazards energy.

As the velocity dependency and forest influence is different for rockfall soil slides and avalanches more details will be given in Sections 3.3-3.4.

3.2.1. Forest effect in hazard path

The premise of protective forest in the path of an avalanche or rockfall is that the forest is able to decrease the energy of hazard by increasing the friction/energy dissipation. We will use the term energy dissipation rather than friction because friction is a force that is applied to a mass and with the FAT hazard model, we assume a non-zero mass but do not account for the mass. Therefore, the term friction can be misleading. The magnitude of energy dissipation by the forest is different for avalanche and rockfall, because the mass movement and its interaction with forest is very different. The energy dissipation applied by the forest is depended on the forest structure and the energy of the hazard. We will describe how energy dissipation is dependent on the forest structure, and the velocity of the mass.

Energy dissipation from a forest will occur when the hazards mass interacts with tree stems, branches and roots. Therefore, the number of trees, shrubs and bushes and the hardness of these objects are relevant to the energy dissipation. There are several common forest measurements/observations that would be appropriate to directly associate with the increase energy dissipation capabilities such as stem density, average stem diameter, standard deviation of stem diameters, and tree hardness. Other common measurements can be indirectly associated with increasing the energy dissipation capacity such as stand height can be used as an indicator for stem diameter or tree species can indicate the hardness of the stems, the age of the stand can relate to the size of stems or hardness of the wood.

In order to keep input data simple, a FSI index was created. The index is used to summarize the forest structure in terms of energy reduction. It is up to the user to set the correct FSI; however, default values are available for three groups of forest type if needed: a) evergreen forest, b) deciduous and mixed forest, or c) krummholz, bushes and shrubs. The FSI is a comparison to the optimal protective forest for a specific forest type and hazard (e.g. an average evergreen forest is better at stopping avalanches than mixed forest but worse at stopping rockfalls).

The FSI is then used to adjust the runout angle α. A linear function is used to scale the maximum increase to runout angle or α_{max_forest} with the FSI. α_{max_forest} is the maximum increase to the α angle due to a perfect protective forest. Equation 1 shows how the FSI is used to scale the α_{max_forest}:

$$\alpha_{effective} = \alpha \times \alpha_{max\ forest} \tag{1}$$

To scale the forest effect with the energy of the hazard a simple linear scale is used. The linear scale is tied to two points: the maximum effect is when energy is low (~0) and the forest effect is FSI × α_{max_forest}, or the maximum forest effect for a forest with that particular FSI. The second point is no forest effect when the hazard has a critical high energy (the critical high energy is hazard dependent; Table 1). As stated in deliverable DT.3.2.1., the effectiveness of the forest to slow a mass moving down on a slope, is co-determined by velocity. Therefore, we use the relationship between the empirical runout angle (α) model used in FAT and a similar model that can be derived from a very basic physical model assuming Coulomb friction since the empirical and the physical model result in the exact same equation. In Figure 1, z_{δ} can be interpreted as the square of the velocity, assuming there is a non-zero mass. The increase to the runout angle in forested areas is reduced when the mass has high velocities. In modelling terms, the increase to the runout angle is scaled to the magnitude of z_{δ}.

Table 1. The runout angle for the different natural hazards and the maximum increase to runout angle which would be due to a very good protective forest (FSI = 1).

	NATURAL HAZARD		
	Rockfall	Avalanche	Soil slide
Runout angle (α)	32°	25°	Channelized – 22° Nonchannelized - 28°
Maximum increase to runout angle (α_{max_forest})	13°	10°	- -

It is possible that landslides demonstrate a forest effect along the path, however there is a lack of process understanding of how forest interact with landslides in motion. Therefore, the forest effect along the path for landslides are omitted in the FAT's hazard models.

3.2.2. Forest effect in hazards release area

Protective forest located on the release areas of avalanches and soil slides reduces the probability of the occurrence of the hazard. Since rockfalls often occur on cliffs or areas without forest there is no forest effect for rockfall release area.

3.3. Avalanche

In the following section we give an overview of forest protection effect against avalanches; for more please see Deliverable DT1.3.2 (*Assessment of forest protection effects and function for natural hazard processes*).

Forests growing in avalanche terrain are able to reduce the probability of slab avalanche formation and release (Schneebeli and Bebi, 2004), as well as runout distances of small to medium size avalanches that are released in forest gaps or slightly above the tree line without significant forest damage (Teich et al., 2012a). However, also for larger avalanches, forests are still able to dissipate some energy from the flowing avalanche by breaking, uprooting and overturning the trees in the avalanche path as well as by woody debris entrainment (Bartelt and Stöckli, 2001; Teich et. al, 2012a; Takeuchi et al., 2018), but this effect is often marginal and can result in a higher destructive potential due to trees that are transported downhill in the avalanche debris. Therefore, forest cover extent and forest structure in terms of canopy cover, stem density, species composition and size and distribution of forest gaps, directly influence the activity, i.e. frequency and intensity of avalanches in forested terrain (Bebi et al., 2009; Teich et al., 2014; see D.T1.3.2 for more information). The main protective effect of forest against avalanches is on avalanche release. For previously released avalanches, the secondary protective effect of forests on avalanche runout becomes relevant, i.e. mass reduction by snow detrainment, deceleration and even stopping (Bartelt and Stöckli, 2001; Anderson and McClung, 2012; Feistl et al., 2014). Within the first 100-200 m of an avalanche path, evergreen forests with a high stem density and dense canopy cover can significantly reduce runout distances of small to medium size avalanches (Teich et al., 2012a).

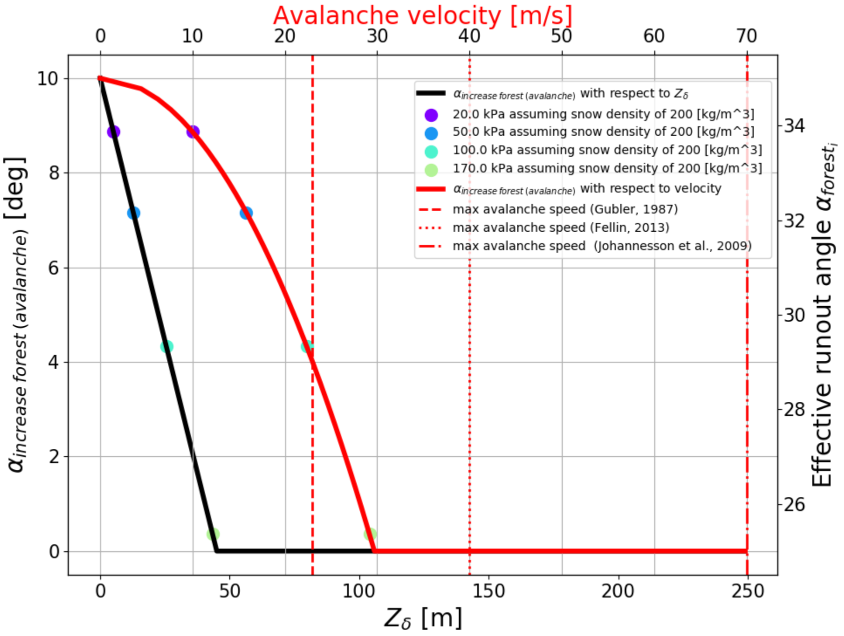

Figure 2. Relationship between z_δ (lower x-axis, black line), the increase to the α-angle in forested areas (left y-axis), the effective runout angle including the increase due to forest (right y-axis), and avalanche velocity (upper x-axis, red lines). That is, studies have found effects of forest on velocity, which can be linked to z_δ and, therefore, to $\alpha_{avalanche\_forest\_i}$.

Figure 2 shows the relationship of z_δ, the avalanches velocity (in red) and the effective runout angle (including the FSI increase due to forest). At $z_\delta = 45$ m (or velocity ~30 m/s) the forest is no longer capable to reduce the avalanches energy according to Feistl et al. (2015) and Takeuchi et al. (2018), which is reflected in the hazard model. This value is reasonable when compared to the Swiss classification according to avalanche impact pressures and potential damages (Table 2; Rapin, 2002). At 30 m/s an avalanche with snow density of 200 kg/m^3 would have a 170 kPa impact pressure, which is a larger impact pressure than is needed to destroy a large well developed forest and uproot large conifer trees. There is a limit imposed at $z_\delta = 250$ m or at a velocity of ~ 70 m/s based on Jóhannesson et al. (2009).

The reduction in release probability is embedded in the avalanche hazard model and is a result of adapting the forested runout angle based on FSI (Table 3). If an avalanche starting area is identified in forested terrain, the increase in runout angle due to the forest can stop the propagation of the avalanche before it starts. By definition the avalanche start point will have a $z_\delta = 0$ and thus a velocity of 0. Therefore, the effective steepness of the terrain to start an avalanche is the $\alpha_{effective}$, as shown in Equation 1.

Table 2. Swiss classification according to impact pressures and potential damages (Rapin, 2002).

Impact pressure (kPa)	Avalanche type	Potential damages
1-3	POWDER SNOW/AEROSOL	Destroys lonely tree (without forest protection).
1-4		Breaks the windows.
> 5-10		Destroys the forest.

3-6	DENSE SNOW	Pushes the gates, brooks/crushes walls, roofs.
3		Turnaround of freight car (18 t).
8.5		Turnaround of a locomotive (120 t).
10		Serious damage of timber structures.
20-30		Destroys timber structures, breaks the trees.
50-100		Destroys a well-developed forest.
100		Pulling out large fir trees.
>300		Movement of large blocks.
1000		Movement of the reinforced concrete structures.

An example is an evergreen forest of highly effective structure with regards to avalanche energy dissipation (FSI = 1) can nullify potential avalanche release areas starting on slopes of ≤ 35°, while forest with lesser capability of adjusting the runout angle (FSI < 1) can stop avalanches from starting on slopes < 35°. Avalanche release areas > 35° are not capable of being changed with this method, i.e. an avalanche will start despite the existence of forest. This is consistent with findings that avalanches can still release in and flow through forest on steep terrain (Bebi et al., 2009; Teich et al. 2012b).

Table 3. The maximum FSI values and default FSI values for the different forest types that are used in the FAT model for avalanches. For justification for forest type specific default and maximum forest structure limits see Bebi et al. (2009), Teich et al. (2014) and Feistl et al. (2014); however, we do not use the exact reported values but rather the ranking of different forest type.

	FOREST TYPE		
	Evergreen coniferous forest	Deciduous and mixed forest	Krummholz, bushes and shrubs
Maximum forest structure index (FSI)	1	0.8	0.2
Default forest structure	0.8	0.5	0.2

3.4. Rockfall

In the following section we give an overview of forest protection effect against rockfalls; for more please see Deliverable DT1.3.2 (*Assessment of forest protection effects and function for natural hazard processes*).

The main protective effects of forests against rockfall occur in the transit and deposit zones. Single trees dissipate energy of a rockfall impact by local penetration of the rock into the tree stem, deformation of the stem, rotation or translation of the root or rebound of the rock. Various studies analyzed the energy reduction capacity of different tree species through winching tests, dynamic impact tests and in-situ rockfall experiments (e.g. Stokes et al., 2005; Dorren and Berger, 2006; Dorren et al., 2006; Bertrand et al., 2013). These studies indicated a strong relationship between stem diameter and maximum amount of block energy reduction. Broadleaves-dominated forests including conifer species that tolerate shade such as silver fir and Norway spruce reach higher stem densities and high basal areas, and have been proven to be very effective (Dupire et al., 2016). In general, broadleaved trees are more resistant against rockfall impacts than coniferous trees (Dorren et al., 2005, Stokes et al., 2005). Thus, the higher the proportion of broadleaved trees in mixed forest types, the higher is the reduction of the runout distances as well as of kinetic energy values of the falling blocks (Dorren et al. 2005). Stem density highly influences rockfall velocity and rebounding heights dependent on kinetic energy reduction caused by the rocks hitting trees (Dorren et al., 2005). For this reason, stem number per hectare is the main forest parameter, which determines the effectiveness of the protective function of a stand (Dupire et al., 2016). One protective forest management guideline indicates a minimum stand density of 400 trees/ha without considering block dimensions (Wasser and Frehner, 1996). The Swiss guideline NaiS (*Nachhaltigkeit und Erfolgskontrolle im Schutzwald*) suggests at least 200 trees/ha with a mean DBH > 36 cm in optimal conditions, and less than 150 trees/ha for the worst conditions (Frehner et al., 2005). These guidelines also mention that distances between trees in the fall direction should be less than 20 m, because falling blocks reach their maximum speed within 40 m, if no impact occurs (Dorren et al., 2005). The influence of forest top height is the opposite to stem density, i.e. higher top heights were found to be linked to longer rockfall runouts (Scheidl et al., 2020). A forest that shows the highest effectiveness against rockfall is, therefore, characterized by a high stem density and a high percentage of broadleaved tree species. The high stem density increases energy dissipation of blocks and reduces velocities. The optimal forest stand to withstand a rockfall hazard in the Alpine Space is coppice forest with shrubs, a high stand density and an average top height, which can reduce the rockfall hazard by 20% (Scheidl et al., 2020).

Increase of α-angle by a maximum of 13° in forested areas which will be scaled by the FSI. Table 4 shows the maximum FSI values and default FSI values for the different forest types that are used in the FAT model. Field experiments and simulations have shown a range of increase of the α-angle between 6° and 14° due to forest over the full path (Dorren et al., 2005; Oswald, 2020). We chose to use a value on the higher side of this spectrum, because the hazard model only applies the increase to runout angle in forested areas.

Since we assume an angle of 32° for the transit of rockfall events and release areas ≥ 45°, a maximum forest effect of $\alpha_{max\_forest} = 13°$ is the maximum increase to the α-angle that can be applied before it would affect the model used to identify starting areas. This is because $32° + 13° = 45°$ and, therefore, an $\alpha_{max\_forest} > 13°$ would meet the stopping criteria and stop the rock before it moved from the starting raster cell.

Table 4. The maximum FSI values and default FSI values for the different forest types that are used in the FAT model for rockfalls. Default FSI-values were applied, if no level 3 data (forest structure information) was available.

	FOREST TYPE		
	Coppice, broadleaved and mixed forest	Coniferous forest	Bushes and shrubs
Maximum forest structure index (FSI)	1	0.8	0.2

Default forest structure	0.8	0.64	0.2

Figure 3 shows the relationship of z_δ, the rockfall velocity (in red) and the effective runout angle (including the FSI increase due to forest). The literature has stated that forest has an energy reducing effect when rocks have speeds of < 25m/s, which can be seen with the orange line in Figure 3 (Jahn, 1988; Zinggeler, 1990; Gsteiger, 1993; Doche, 1997; Dorren et al., 2004; Perret et al., 2004). To be consistent with the literature a cut-off was made above 25 m/s to keep the forest effect at 25 m/s in a range that has significant energy reduction. When the rock has energies more than z_δ = 46 m (or velocity = 30 m/s) there is no longer any forest effect in the FAT rockfall model. A linear relationship between z_δ = 0 with maximum energy dissipation and z_δ = 46 m with no additional energy dissipation was used.

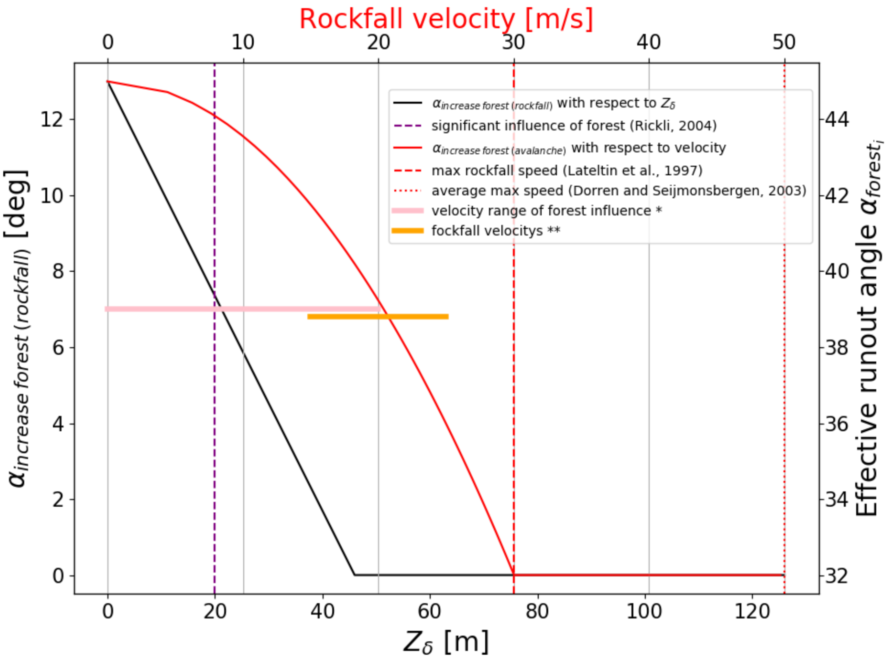

*Figure 3: Relationship between z_δ (lower x-axis, black line), the increase to the α-angle in forested areas (left y-axis), the effective runout angle including the increase due to forest (right y-axis), and rockfall velocity (upper x-axis, red lines). That is, studies have found effects of forest on velocity, which can be linked to z_δ and, therefore, to $\alpha_{increase\_rockfall\_forest}$. The pink and orange lines are velocity ranges where forest had been proven to have an effect (pink; Rickli et al., 2004) or in forests measured rockfall velocities (orange, **; Jahn, 1988; Zinggeler, 1990; Gsteiger, 1993; Doche, 1997; Dorren et al., 2004; Perret et al., 2004).*

3.5. Shallow landslide

In the FAT tool spontaneous shallow hillslope landslides of loose material (soil, debris, mud) are modeled. There are two characteristics used to describe a shallow landslide: a) the release mechanism, and b) the behavior of the mass movement. The release mechanism for the shallow landslides primarily models rupturing or slumping. The characteristics of the body movement is sliding which can liquefy if there is sufficient water content. Because there is a big difference in behavior between sliding and flowing motion there is a considerable amount of variation of runout distances of shallow landslides. The FAT considers large to very large events (but not extreme events) in the hazard models. Therefore, the runout angle used reflects shallow landslides that probably have a higher water content and start to flow rather than slide down the slope.

We assume that the forest does not interact with the shallow landslide after release. This assumption is necessary because there is a lack of process understanding and literature on how the forest interacts with a moving body of earth. Therefore, the forest effect for shallow landslides only occurs for the release. Tree roots are the primary pathway to reduce the occurrence of shallow soil slides. The trees roots can anchor the topsoil to prevent release and some roots can even penetrate to deeper soil layers. In FAT the way the forest effect is expressed is the difference in relative likelihood of an event. In Figure 4 the blue line shows the relative likelihood of an event dependent on the slope of the terrain. At 40° slope angle there is a maximum for relative likelihood. The green line shows that when forest is located on the release area of a shallow landslide there is a much reduced relative likelihood that the slope will produce an event. The red line shows the forest effect, or the difference between the relative likelihood between forested and unforested release areas.

It is important to note that for shallow landslides we do not consider the forest structure or forest type when calculating the forest effect. Again this is due to a lack of process understanding and literature. FAT only checks if the release area is classified as forested by the user.

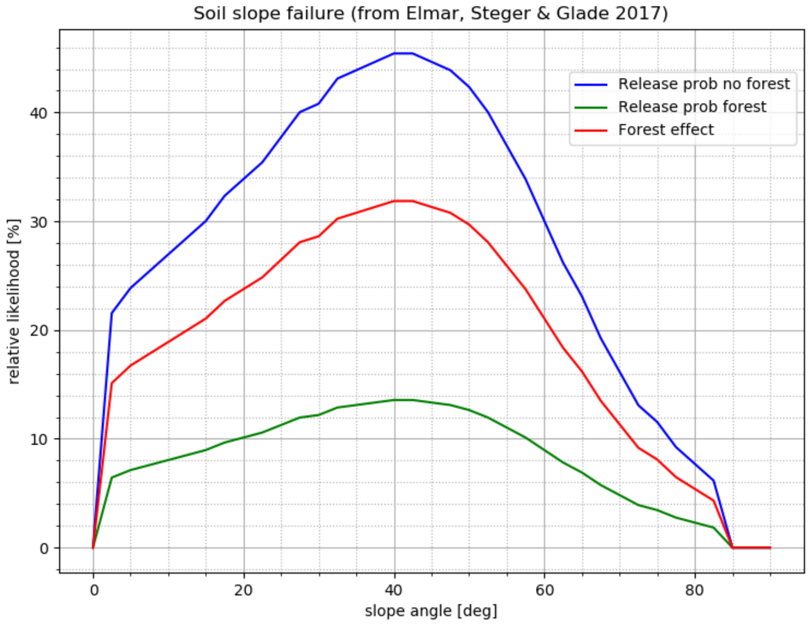

Figure 4: This plot shows the relative likelihood of a shallow soil slope failure as a function of the hill slope angel. In blue is the likelihood of an event without forested on the release area, where green shows the likelihood of an event when the release area is covered with forest. The difference between the curves is shown in red which is the protective forest effect with regards to likelihood of an event.

4. ECONOMIC MODEL

The possibility to test alternative solution (green, grey and avoidance measures) allows their comparison in terms of cost and effectiveness of technical and biotechnical protection measures against the cost of managing and maintaining of a protective forest.

The economic routine of FAT tool is called TEGRAV (TEchnical – GReen – AVoidance). The TEGRAV performs a cost-benefit analysis of nature-based, land use avoidance and technical protective measures (and their combination), allowing for their comparison by the user of the FAT. The economic aspects considered for each protection measure are four (also the main outputs of the analysis):

- **Direct costs:** originating from construction/implementation cost plus maintenance costs, plus dismantling cost.
- **Indirect costs:** originated by the construction/implementation of the measure, which presumably modify an existing situation.
- **Avoided damages:** all the different detriments to infrastructures, people and assets that could happen without protection measure.
- **Benefits:** the sums saved or earned due to the construction/implementation of the measure.

The main element of novelty of this approach stays in the possibility to recognize the potential benefits of considering the protective forest as a protection measure to be adopted instead of, or together with, the other grey and land-use solutions. Moreover, Eco-DRR solutions often proved to be more cost-effective than grey measures, also implying little or no drawbacks in their implementation. On the other hand, its aim is not to design real-life protection measures on exposed assets and neither to achieve quick, ready-to-use cost-benefit analysis of projected interventions, but it is only meant as a tool to display the potential for alternative solution to the current practices.

The TEGRAV assesses costs and benefits of each protection measure selected by the users among a wide list of possible solutions developed with the goal to cover the most frequent solution currently adopted in the Alpine Space. To each of them were assigned standard economic values based on the country or region in which they were implemented, in order to obtain results in line with the geographic location of the profile. As mentioned above, these standard values are then combined with the input data provided by the user (asset location and typology; profile width; …) in order to provide profile-specific economic results of the different protective solution available.

The protection measures in the analysis are divided into green measures, grey measures, and avoidance measures.

1. GREEN MEASURES – categorized as a “natural” protection against hazards → protective forest.
a. Forest rehabilitation;
b. Afforestation of the profile (Wooden tripods + plantation for rockfall and avalanches).

2. GREY (TEHNICAL) MEASURES – protection infrastructures predominantly made of concrete and steel.
a. Rockfall nets;
b. Snow fences /steel snow bridges for avalanches;
c. Retentions dams (for all 3 processes).

3. AVOIDANCE MEASURE – avoiding the risk of being exposed to the hazard.
a. Road closure;
b. Building closure;
c. Building relocation;
d. Generic soft measures (rapid alert systems, communication initiatives)
e. Temporary measures (artificial releases).

Cost-benefit analysis is performed for three hazards: avalanches, rockfalls, and soil slides separately. Each hazard has specific measures that are considered in the analysis (Figure 5) since different measures are used for different hazards. At the potential release area, two types of measures are considered for avalanches: technical release control (grey measure) and artificial release system (avoidance measure). For rockfalls at the transit and runout area only rockfall nets (grey measure) are being considered. For debris slides, the only technical measure considered is the retention dam (in the runout area).

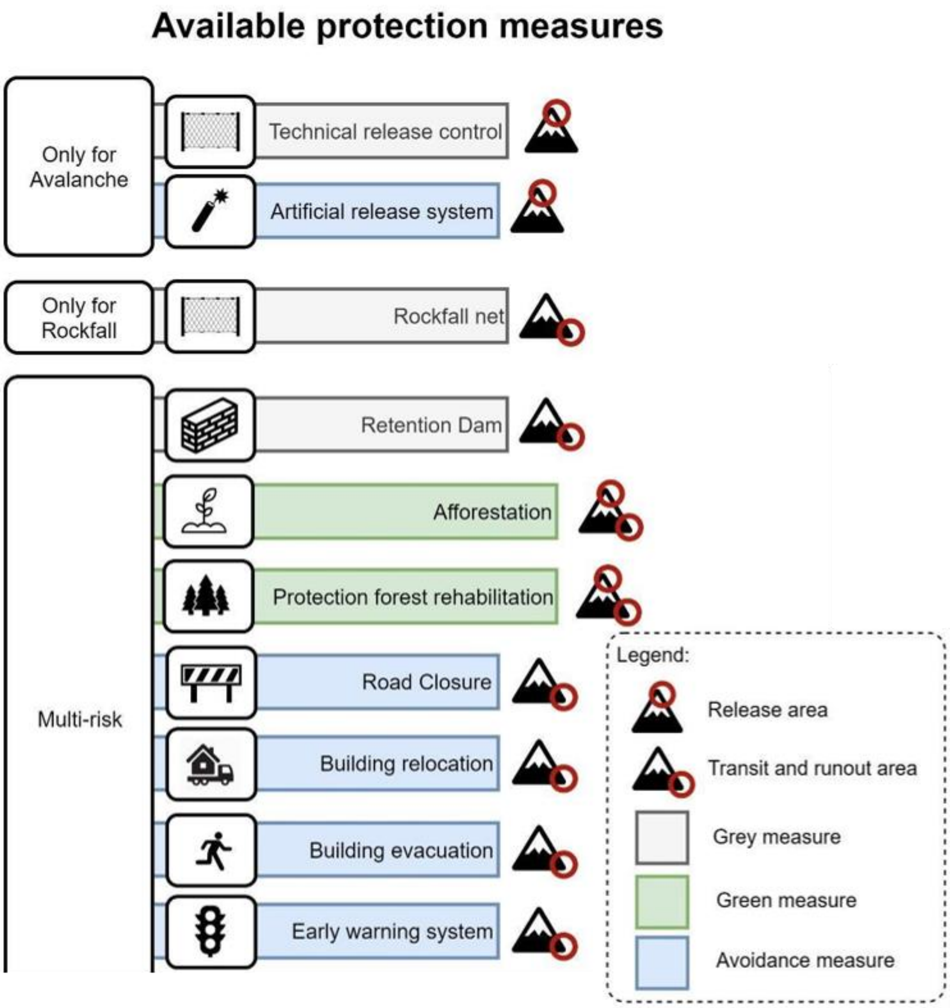

Figure 5: The list of protection measures that are in FAT tool applied only for individual natural hazards.

Some of the measures (Figure 5) can be applied in the case of all three hazards (multi-risk approach): retention dam for transit and runout area (grey measure); afforestation and protection forest rehabilitation for release, transit and runout area (green measure); road closure, building relocation, building evacuation, construction ban, and early warning system for transit and runout area (avoidance measure).

The inputs that the user has to enter to the FAT tool for individual economic-hazard routine area are:

- list and info on exposed assets;
- width of the profile;
- eventual length of the detour to reach a destination.

Additional information and more detail explanation on the economic routine and the TEGRAV tool can be found in the two dedicated deliverable D.T3.3.1 “TEGRAV analysis: an integrated model to compare risk management strategies”, and D.T3.3.2 “Report on TEGRAV tool” on the project’s webpage.

4.1. Green measures

Forest rehabilitation is the management of forest to bring it from a less optimal structure with regards to protective effects to a forest structure which is optimized for protective effects. The optimal protective effects for a given forest depend on the elevation and forest type. Rehabilitation measures are done by creating an advantageous environment, which will stimulate forest development in a way to maximize its protective effects. Since forest growth takes a considerable amount of time and drives the development of the protective effects, the forest rehabilitation measure is assessed at three different times at 0, 10 and 20 years. The costs of the measure will add up over time while the avoided damages will increase with the development of forest structure and protective effects.

With the **afforestation** measure we consider both the afforestation of the chosen section of the profile and the installment of wooden tripods, which allow the forest to grow at its early stages without it being limited by the snow gliding and provides some protection in the first years after the plantation. Since forest growth takes a considerable amount of time and the protective effect changes with forest development, the afforestation measure is assessed at four different times from afforestation to mature forest. The first time step is when the afforestation measure is implemented (year 0), and then after year 25, 50 and 100 to assess the protective effect at different forest development stages, which span from forest establishment and young forest to mature forest. The costs for the measure will add up over time while damage avoidance will increase with increasing protective effects dependent on forest structure.

4.2. Gray (technical) measures

Snow bridges are technical structures installed in the release area of an avalanche to stabilize the snowpack, reduce snow gliding and prevent avalanche release. The costs per unit of a steel snow bridge is dependent on the depth of the snowpack that they are built to stabilize. Deeper snow depths require taller structures and stronger support. Three maximum snow depth ranges were used to estimate the costs of the steel snow bridge protection measure.

Rockfall nets are technical measures used to prevent rocks and debris from falling onto assets at risk. The size and strength of rockfall nets are estimated as a function of the modeled energy and jump height of a block at that location. Therefore, the net will be taller, stronger and more costly in the middle of the rockfall track in contrast to shorter and less expensive nets located in the runout areas where the rock is traveling slower and the modeled energy is low. The cross-slope width of the nets is equal to the average profile width chosen by the FAT user.

Catching dams are technical structure used to stop the dense flow part of an avalanche as well as the denser part of a soil slide and the rocks in the runout area. As for the rockfall net, the catching dam's height is estimated as a function of the modeled energy of the avalanche at that location. Therefore the dam will be taller and more costly in the middle of the avalanche track. Compared with shorter and less expensive catching dams located in the runout areas where the avalanche is traveling slower and the modeled energy is low. The cross-slope width of the dam is equal to the path width chosen by the FAT user.

4.3. Avoidance Measures

Road closure is an avoidance measure that can be used when the asset at risk is a road or railway. As part of this measure, costs for detour (the costs associated with the extra distance that must be traveled to avoid the road or railway closure) are considered as indirect costs. The detour cost per km is fixed at 3 €. The length of the exposed road is equal to the path width as defined by the FAT user and the damage potential depends on the type and length of the road that is exposed to the hazard.

Building evacuation is used when a building, and therefore the people living or working in it, is endangered. The building, however, will still get damaged by the hazard. We assume that the building is evacuated for a short period of time. Therefore, for every person that gets evacuated accommodation costs of 40 € have to be accounted for. However, if longer periods of evacuation are needed these costs will be much higher.

A **building relocation** is the process of moving a building / infrastructure from an exposed location to a safe location. This measure is applied only in rare cases and technical protection measures reducing the impact of the natural hazard process are usually favored.

An **early warning system** is a measure made up of two parts: a doppler radar system (used to monitor slope movements) and a traffic light system. We base this calculation on the average costs of a system from the company Geopraevent with a lifetime of 20 years. As part of this measure, the costs deriving from the road closure and hence the detour that cars have to take are considered as indirect costs. The cost/km is fixed at 3€ as for the “road closure” measure.

Artificial avalanche release is a measure used to avoid the formation of large avalanches by periodically triggering smaller avalanches. In the FAT Tool we considered a bombing tower. The material costs for a bombing tower are 80000 € and its installation (including helicopter transportation) amounts to 20000 €.

4.4. Graphical user interface (GUI) and wireframe of the FAT tool

Simultaneously with the development of tool’s content, a graphical user interface (GUI) for Forest Assessment Tool (FAT) was developed. GUI supports all described procedures and calculations in order to presents them to user in a graphically clear, simple and appealing way. The main graphical principles that were followed at FAT tool design were:

- clarity – the FAT tool site answers the questions what a user can do at each site place and in a sequence of predefined steps guides users to achieve their goal (e.g. calculation of the most appropriate protection option);
- simplicity – the information on each page are essential for users to achieve the goal - there is just enough information that don’t distract and over-stimulate a user (e.g. meaningful color use);
- confident – clear calls-to-action increase users’ confidence in using designed tool, the site page is just enough predictable and buttons and boxes are in expected places in a familiar, commonly-used and intuitive positions.

A wireframe for GUI is developed following previously mentioned rules of clarity, simplicity and users confident. The key and common elements of all pages are short title at the top of the page guiding user through a process of steps achieving a final goal. On the left side of the page a user can find an index with previously described titles which enables easy transitions between the pages (e.g. if user wants to change/add anything in previous steps after he moved on following pages). The index also serves as an orientation to what follows in next steps. Transitions between pages are enabled by previous and next buttons intuitively placed at the bottom of each page. Another common element on pages are instruction paragraphs at the top of each page, guiding and encouraging the user on how/where to input data. Additional explanations on specific terms are provided by info buttons next to each term. The explanation appears in a form of pop-out boxes. The insertion of data for specific fields is provided by selection from drop down menus/manual input of number/ selection of predefined term. When profile is selected/uploaded a user can manually define the location of measure on the selected profile. The graphical language follows GreenRisk4ALPs representative color scheme.

A step-by-step procedure is structured in a following way:

- welcome page – provides essential information on FAT tool and its development with external links to more in-depth explanations, a tutorial video on FAT use is attached and external links to project's official web site, as the application is available in all project partners languages, a user selects desired language at the top of the page;
- select process – user selects a process he wants to model;
- define profile – user defines/uploads a profile location (country) and its characteristics (e.g. width);
- define parameters – the selected forest and infrastructure parameters of measures are defined;
- select protection measures – protection measures can be selected from each group of measures and defined in detail;
- results – results are presented in a ranking of the measures selected by the user in terms of cost/benefit: the lowest the ratio the higher the ranking - that is graphically presented by circles of different sizes – the highest the ranking, the largest the circle is, while the use of color green means positive effect (the larger the green circle is, the more positive the effect or a measure is), and red means the negative effect (the larger the red circle is, the more negative the effect or a measure is);
- success and thank you page – end the process and once again encourages the user to visit official Gr4A page for in-depth explanations .

5. CONCLUSIONS: THE USE OF FAT TOOL

The development of FAT tool aimed at providing a useful and meaningful tool for practitioners to help them choose between the various protection options. The most innovative part of the tool is the importance given to forest and Eco-DRR solutions and the encouragement to choose the protection option, considering both, technical and economical point of view.

The tool has been built to be graphically appealing, simple and user friendly. Each step of the process is thoroughly explained, and each value used in the model is justified. The tool guides the user through the selection of the input data and through the understanding of the final results. To make the results even more understandable and accessible to the final user a graphical representation of them has been preferred to a numerical one. As stated before, the tool aims to be a decisional support mean for practitioners and administrations, however, for it to be applied in different alpine contexts, a lot of approximations has been made and providing the user with exact numerical result could be misleading.

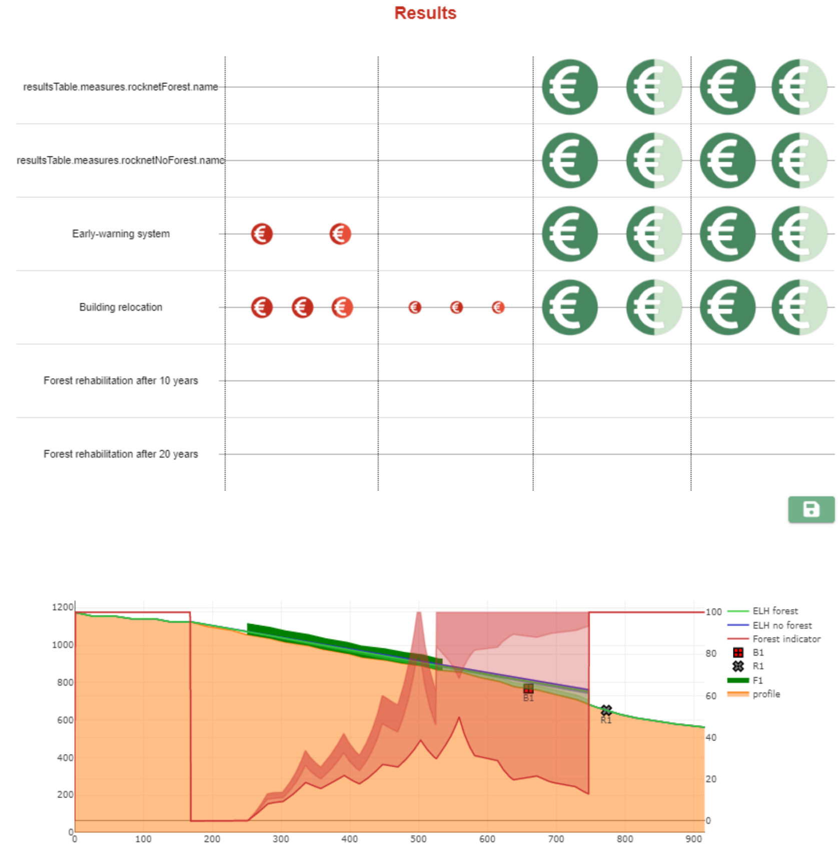

Figure 6: An example of the results provided by the FAT tool.

The FAT tool will be available online translated in five languages: English, French, Italian, German and Slovenian. Online tutorials will be provided in each language to help the users better understand the workflow and the expected results.

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