# Approved examples of operational deployments of ASFORESEE

WP4 - Deliverable D.T4.5.1

Alpine Space Project 462: RockTheAlps

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# 1. Introduction

The protection of populations, infrastructures and economic activities in the mountain area is of primary importance and mountain forests, if properly managed, offer an effective protection service that integrates with engineering solutions. Many studies have been conducted to quantify the importance and dynamics of the protective function performed by forests, but few have also considered economic aspects, obtaining different results depending on the methodological approach used.

In order to evaluate in a standardized way the economic value of the protection service provided by forests, the partners of the WP4 of the Interreg Alpine Space project: "RocktheAlps" have developed a harmonised methodology at the Alpine Space level to provide such evaluation against a specific natural hazard, that is rockfall (Dorren et al., 2005). The application of this model, moreover, will also allow the cross comparison between case studies from the different Alpine countries. Briefly retracing the steps and deliverables carried out within the duration of the project:

- **deliverable D.T4.1.1 "State of the Art of Forest Protection Service Economic Assessment"**: more than 20 case studies have been identified in the literature, which are however characterized by a wide inter-variability, both in terms of the economic method adopted for the evaluation and in terms of the form of expression of the result (Bianchi et al., 2018). This heterogeneity brings to a general lack of agreement on the most suitable methodology to be applied in the evaluation of this ES, undermining its wider adoption in a standardized and replicable way;
- **deliverable D.T4.2.1 "Economic Concepts for Evaluation of Risk Mitigation Strategies"**: described in depth the features of the different evaluation methods available in literature to estimate the value of the regulation ES. This report highlighted the pros and cons of each method and provided a framework to build the ASFORESEE model (Bruzzese et al., 2018);
- **deliverable D.T4.3.1 "ASFORESEE: an AS Harmonized Methodology for Protection FORest Ecosystem Services Economic Evaluation"**: a handbook presenting the ASFORESEE (*Alpine Space FORest Ecosystem Services Economic Evaluation*) model. In the handbook, Accastello et al. (2019) mainly describe its general principles, concepts, workflow of the adopted methods – Replacement Cost Method and Avoided Damages Method (hereafter RCM and ADM) - the economic and technical input data required, the output data and their uses for displaying the economic role of protection forest in rockfall risk mitigation policies/strategies. Methods adopted in ASFORESEE have been chosen thanks to the deliverable D.T4.2.1, as they are replicable, require limited time and input data and their output are easy to understand. The output model is the economic value, in different forms (€, €/ha and €/ha/year), of the protective service offered by the forest against rockfall;
- **deliverable D.T4.4.1 "Case studies database for testing ASFORESEE":** a list of case studies chosen and supplied by project partners in order to test and validate the ASFORESEE model. These study

sites had to be identified on the basis of three fundamental elements: the presence of a protection forest, of a rockfall risk and one or more exposed assets (Bruzzese et al., 2019).

Finally, with this deliverable (**D.T5.1.1 "Approved examples of operational deployments of ASFORESEE"**), has been formalized, in template form, the outputs obtained and the critical analysis coming from the feedback of the ASFORESEE test in each case study.

## 2. Guide to filling in the form

The template is divided into three macro-areas, respectively: the descriptive and framing part of the case study, the technical-economic part with the input data required for the functioning of ASFORESEE and the final part with the results and their discussion. In the descriptive part, in addition to the name of the case study localization and partner who provided it, are required:

- pictures at local and, if possible, national level, in order to frame the case study;
- description of the case study, that is a short text to introduce the readers to the general situation of the case study (e.g., information about the forest stand, the rockfall phenomena characteristics, the human settlement in the area, economic interests, etc.);
- features of case study, that are pictures showing the boundaries of the forest, the rockfall source and the exposed assets.

In the technical-economic part there is a generic section, valid for both methods and a specific section depending on the method chosen. In the first one is required the indication of the chosen method, the evaluation period considered and its motivation, the description of the assets at risk, the type of protection forest (characteristics, specific composition, area, effectiveness, etc.), its effectiveness against rockfall (kinetic energy and ORPI) and the costs of forest management required for the forestry interventions and logging operations carried out during the evaluation period considered (objectives of the intervention, cutting cycle, harvest intensity, assortments, etc.). In the specific part is required for RCM the level of protection desired by stakeholders and the score obtained from the qualitative survey carried out by our research group to implement it within the required level of protection. With regard to ADM, the values of the assets exposed, explaining where they were taken from (pricelists, insurance, literature, etc.).

In the last part are reported the main results obtained with ASFORESEE, namely the overall discounted rockfall net, with and without forest, for the RCM, the overall avoided damage by the forest for the ADM, the overall discounted stumpage value (with regard to forest management) and finally the protective value of the protection service offered by the forest against rockfall (expressed in the different forms reported before). Then, a critical analysis of results is made describing the pros and cons of the evaluation (limitations, assumptions, relevance of the result for stakeholders and decision-makers, etc.).

## 3. List of case studies

Table 1 shows the case studies provided by the different project partners. They have been divided according to the method adopted – RCM and ADM.

**Table 1 -** Case studies.

| Replacement Cost Method | Avoided Damages Method |
|---|---|
| Kaysersberg, France | Cesana Torinese, Italy |
| Noirefontaine, France | Colcuc, Italy |
| Auronzo di Cadore, Italy | Cevo, Italy |
| San Vito di Cadore, Italy | Valdidentro, Italy |
| Strailach, Germany | Cogolo, Italy |
| Podbrdo, Slovenia | Seewände, Germany |

| Case study name: | *Kaysersberg, France* |
|---|---|
| **Responsible partner:** | *BRGM and IRSTEA* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of Kaysersberg.

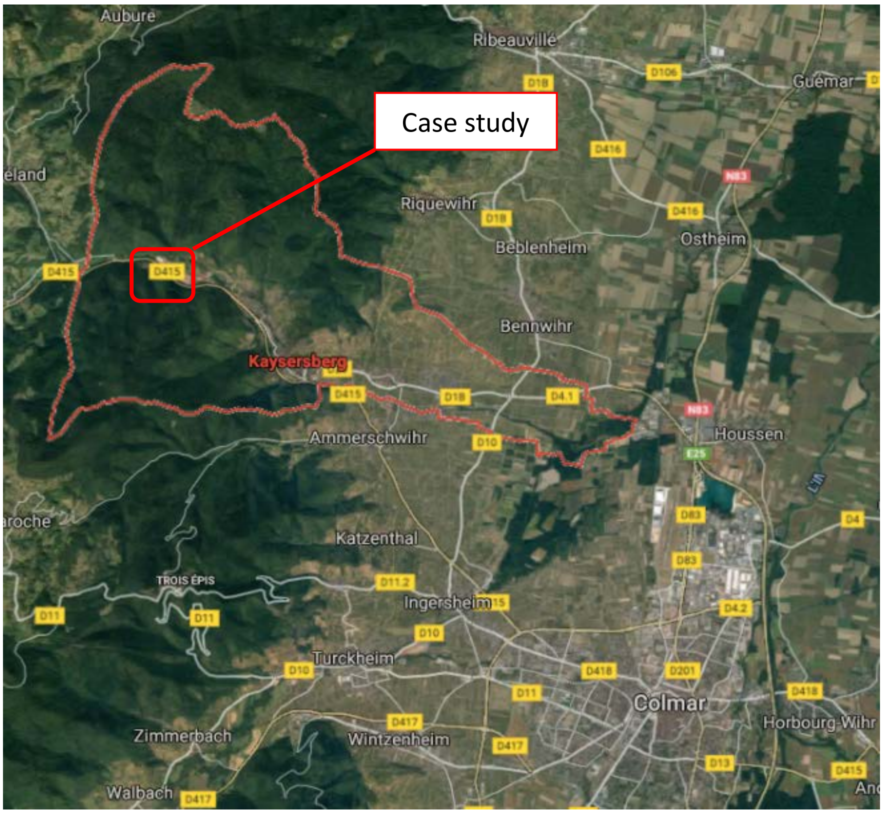



**Figure 2 -** Municipal boundaries of Kaysersberg and localization of the case study.

## *2.* CASE STUDY DESCRIPTION

The case study is located near the road RD 415, on a portion located in the south of the municipal territory of Kaysersberg Vignoble. This site was chosen because of the occurrence of one event having reached the road (year 2017), this road is one of the three ones allowing to cross the Vosges Massif, and the continuous presence of forest upstream of the road. Above this road, an old mature mixed forest (basal area varying from 25 to 41 mq/ha) is established on a regular slope varying between 29° and 32°. The forest zone is dominated by a scree and four rocky outcrops are locally presents in the forest, each with a height of about 3 m to 10 m.

During the event of 2017, the maximal volume of the blocks that reached the road was of about 0.33 mc.

## *3.* CASE STUDY FEATURES

The forest boundaries as show in Figure 3 cover **16,45 ha**. The exposed asset is the road RD 415. A linear length of about 450 m of road is exposed.


**Figure 3 -** Forest boundaries and asset at stake.

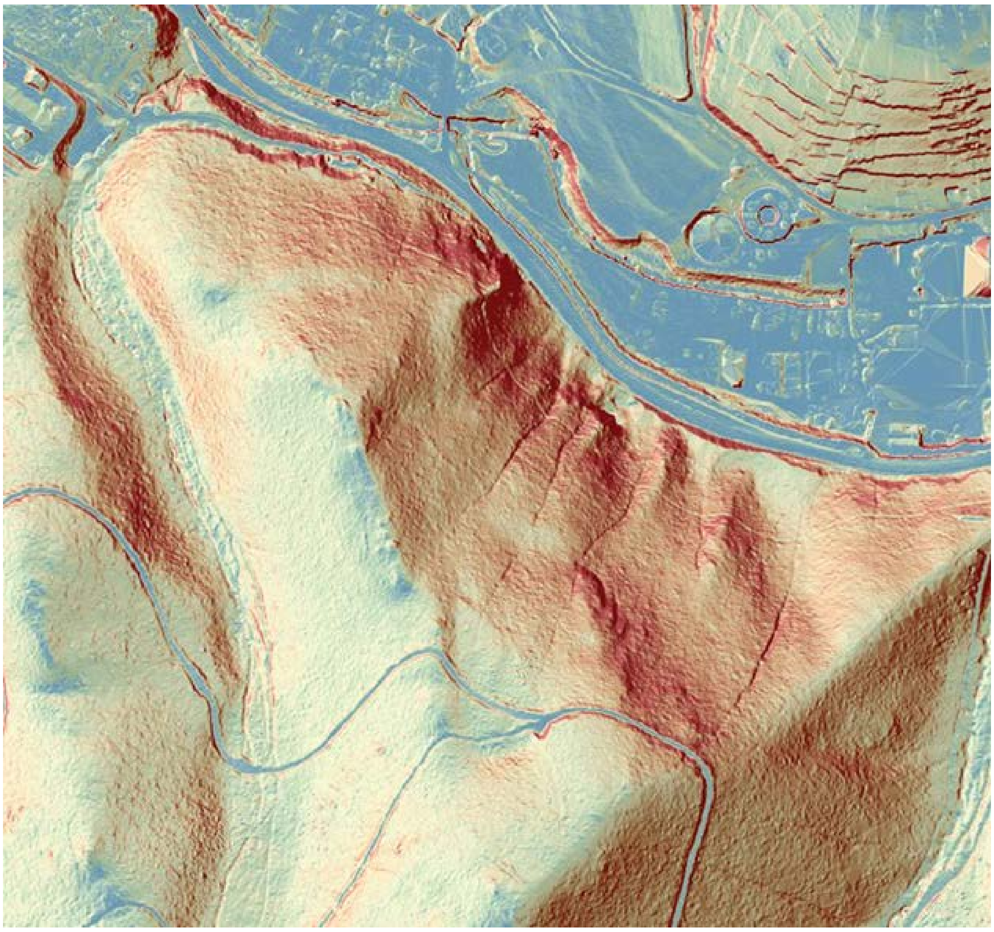


**Figure 4 -** Topography obtained from the LIDAR survey.

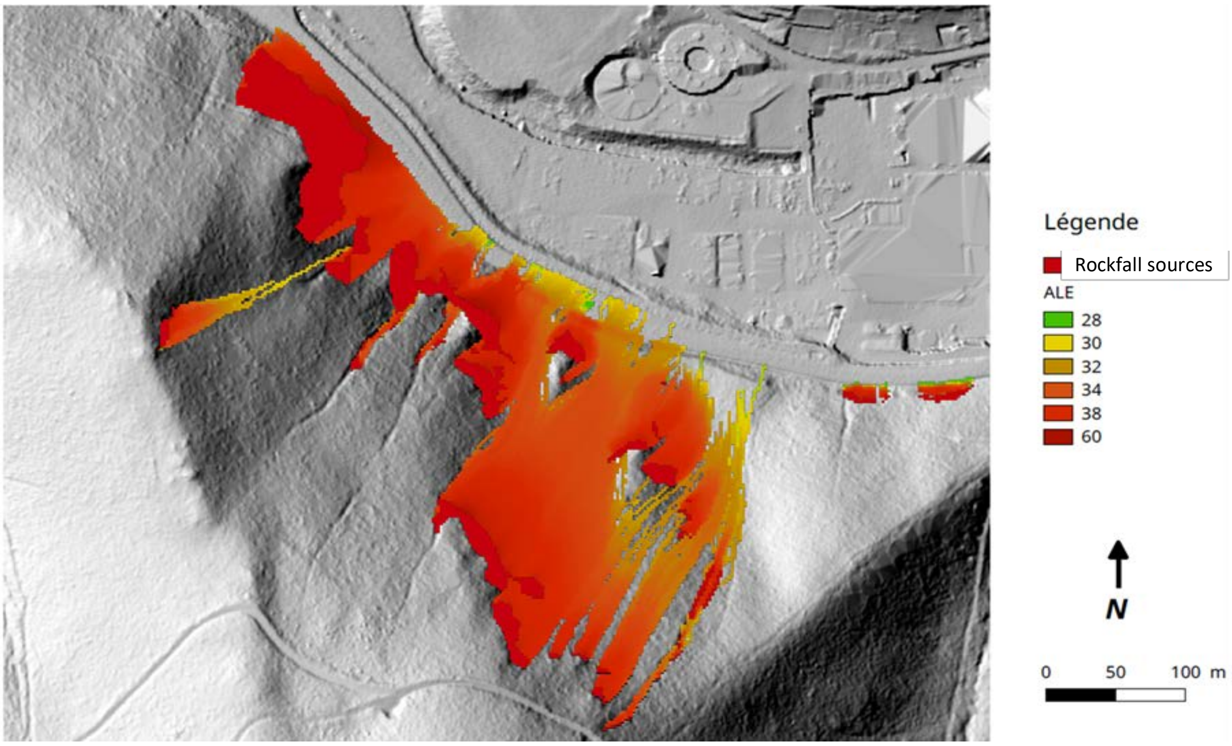



**Figure 5 -** Rockfall sources. This side of the hill produces mainly block of a size inferior or equal to 0.5 mc.

## 4. **ECONOMIC EVALUATION**

- Selected economic approach:

in this case study, an artificial protection is easily implementable and the road to be protected, even if it is quite important for the connection of local territories, is not highly sensitive to the rock fall events. Thus, the **RCM** is the selected approach.

- Selected time period for the evaluation*:*

the timespan selected for the evaluation is of **25 years**. Considering that it is the service life of a traditional protection structure (rockfall net).

- Exposed assets:

the asset exposed to the rockfall is a portion of the **Road RD415**. It is a two lanes road with a width of about 8 m. The average annual daily traffic (AADT) is of about 10,000 vehicles.

- Protection forests:

the five profiles represented in the following figure are representative of the problems of falling rocks and of the different propagation zones.

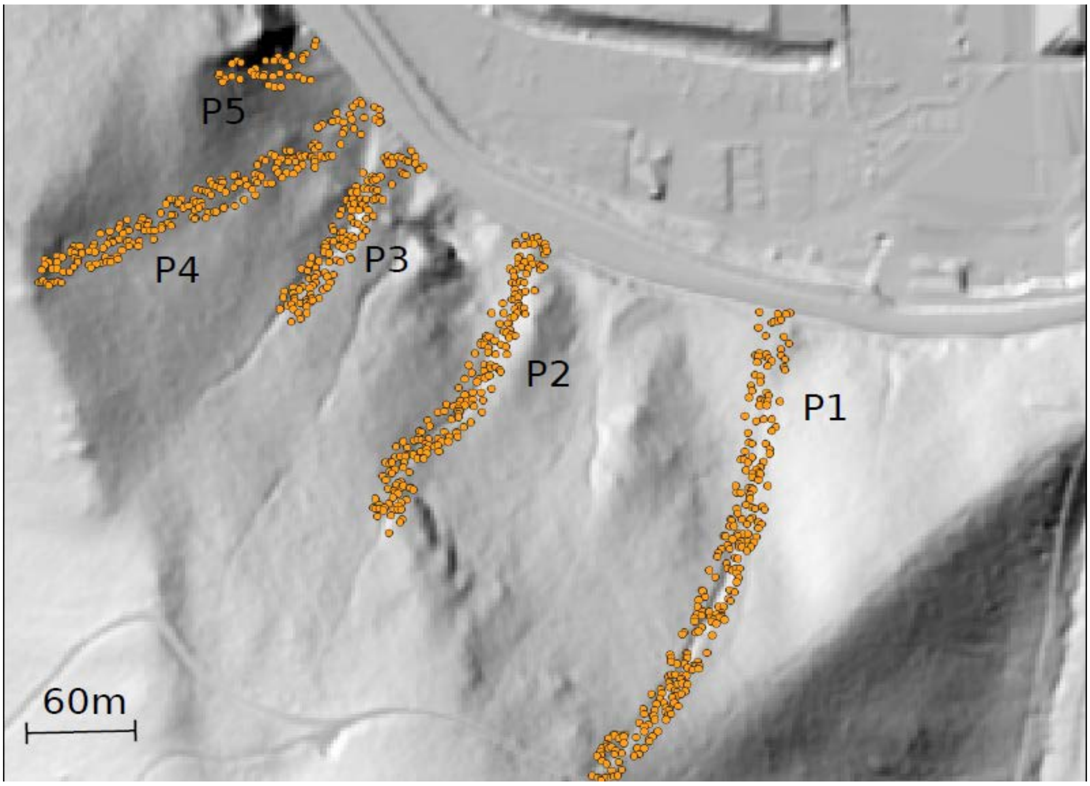



**Figure 6 -** Location map of the five topographic profiles used for the analyses.

A buffer of 10 m on each side of the profiles has been used to extract the identified trees from the analysis of the Lidar data (circles in orange). The methodology used allows to extract the height of the trees identified and to assign them a diameter with an allometric function.

The table hereunder provides a description of the current state of the forest in each profile.

**Table 1 -** Wood characteristics in each of the five representative profiles.

| Profile | Length [m] | Average diameter at breast height [cm] | Density [trunk/ha] | Basal area [mq/ha] | ORPI |
|---|---|---|---|---|---|
| P1 | 310 | 28 | 420 | 25.88 | 99 |
| P2 | 205 | 25.9 | 492 | 25.90 | 97 |
| P3 | 130 | 28 | 545 | 33.59 | 94 |
| P4 | 224 | 33.4 | 464 | 40.68 | 98 |
| P5 | 60 | 31.9 | 328 | 26.26 | 62 |

Using the tool ROCKFOR$^{net}$, in the profiles P1, P2, P3 and P4, the forests stands can provide a protection efficient at 75 % against volumes that are smaller than 0.5 mc. These results are consistent with those obtained by 3D simulation and the distribution of projectiles observed onsite.

- Forest effectiveness against rockfall:

the kinetic energy considered is the one of a falling block having the 95° percentile of the diameter measured in the area. In this site, it corresponds to a block of 0.56 mc. The ORPI index used for calculation is the one corresponding to the worst case profile.

| Asset | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| Road RD415 | 198 | 265 | 62 |

- Desired protection level from stakeholders:

stakeholders desire a very high level of protection because the rock falls threaten a primary road for the territory. The minimal level of protection desired by stakeholders is **75 % to 95 %**. The ideal protection level desired by stakeholders is 95 % to 99 %.
In the ASFORSEE model, the input data "Desired Protection Level from Stakeholders" is set at **95 %**.

- Score of the protection demand survey:

the asset owner and manager of the road have carried out the protection demand survey. The score obtained is **19**.

- Discounted cost of the protective structure:

in the scenario without forest, the investment cost of a protective structure providing the expected level of protection would be of € 162,000. This amount corresponds to the implementation of net over a linear of 360 m with an investment cost of € 450 per linear metre. It should be added the cost of felling 350 trees but being in a "without forest scenario" it seems not relevant to include this cost to the investment cost. The maintenance cost corresponds to two inspections per year for an annual cost of € 500. Using these figures over 25 years with a discount rate of 2 %, the discounted cost of the protective structure is of **€ 171,762**.

## *5.* FOREST MANAGEMENT

There is **no forest management** in the current situation.

## *6.* RESULTS

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | 171,762 |
| **Overall discounted building cost with forest [€]** | 102,821.91 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***68,940 €***
- *Unitary Protection Value* ***4,204 €/ha***
- *Yearly Protection Value* ***131 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

The level of protection offered by the forest in its current state is not enough. The stakeholders and decision makers want to increase the level of protection. They need a decision support to select between two options:

- invest in an engineering solution, which is very efficient but expensive;
- invest in a natural solution, which is less expensive but offers a progressive increase of the protection and a slightly lower level of safety.

The protection value provided by the model correspond to protection service provided by the forest at its current state and does not consider the possible improvement of the protection service that can be reach by implementing a specific forest management. For decision makers it seems that a comparative cost efficiency approach would bring a useful decision support.

| | |
|---|---|
| **Case study name:** | *Noirefontaine, France* |
| **Responsible partner:** | *BRGM and IRSTEA* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of Noirefontaine.

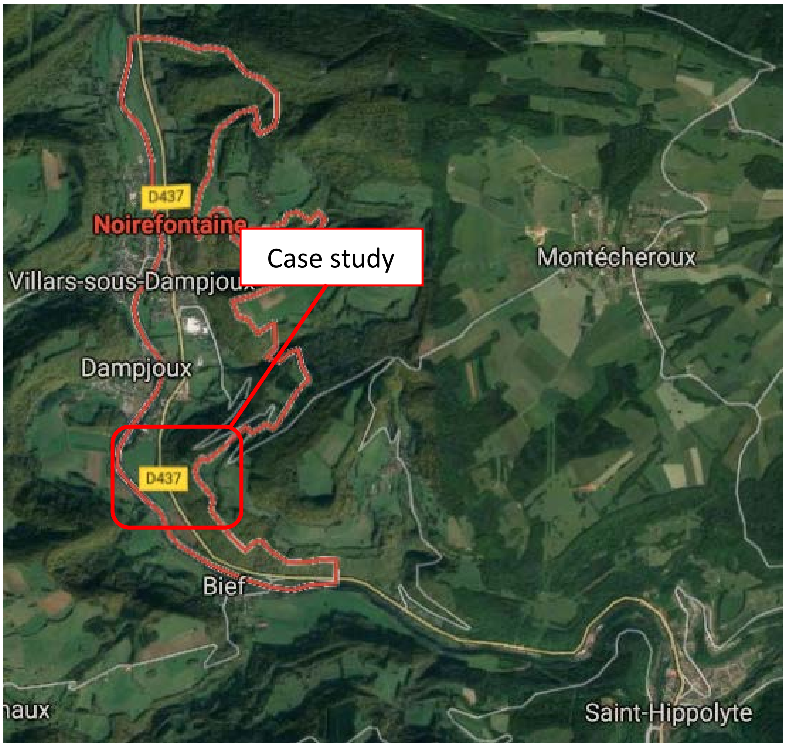



**Figure 2 -** Municipal boundaries of Noirefontaine and localization of the case study.

## 2. CASE STUDY DESCRIPTION

The case study is located near the road RD437, on a portion located in the south of the municipal territory of Noirefontaine. This site was chosen because of the occurrence of two events having reached the road (years 2012 and 2015) and the continuous presence of forest upstream of the road. This road is overlooked by an old railway line forming flat area. Above this railway line, a shallow forest is established on a regular slope varying between 35° and 39°. The forest zone is dominated by three successive rocky outcrops, each with a height of about 10 m to 15 m, separated by low forested areas with a slope like the forest zone.

During the two events of 2012 and 2015, the volumes of the blocks that reached the road were 1.6 mc and 2.1 mc.

## 3. CASE STUDY FEATURES

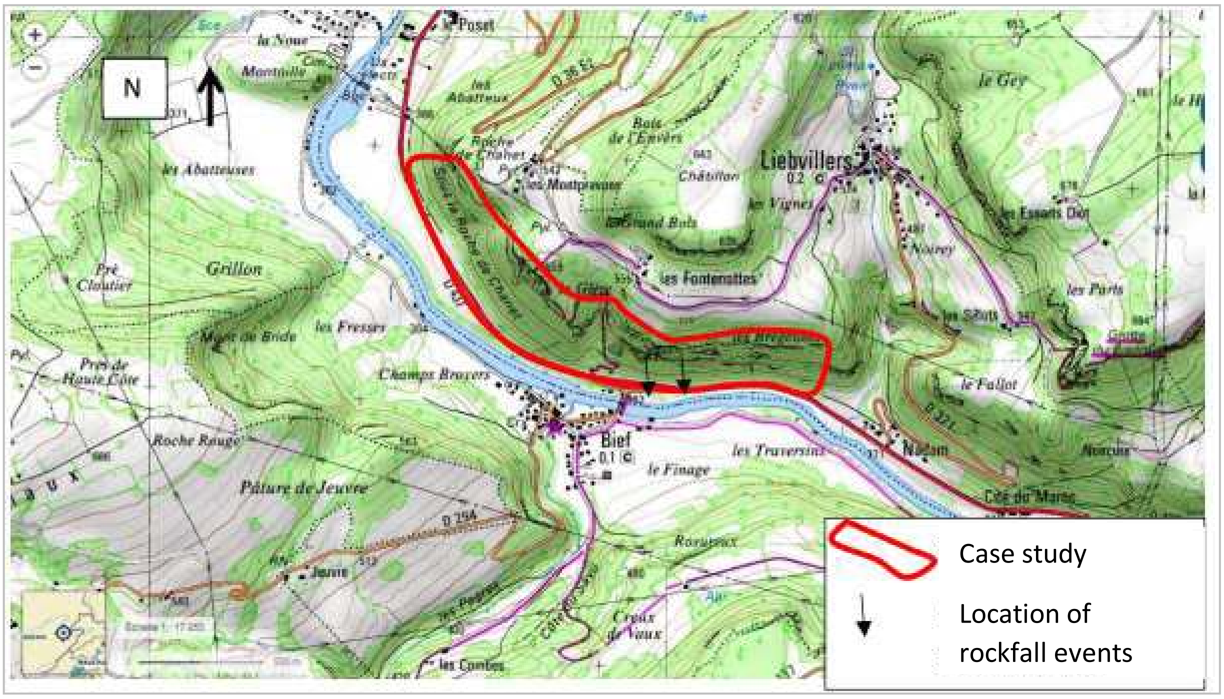



**Figure 3 –** Case study.

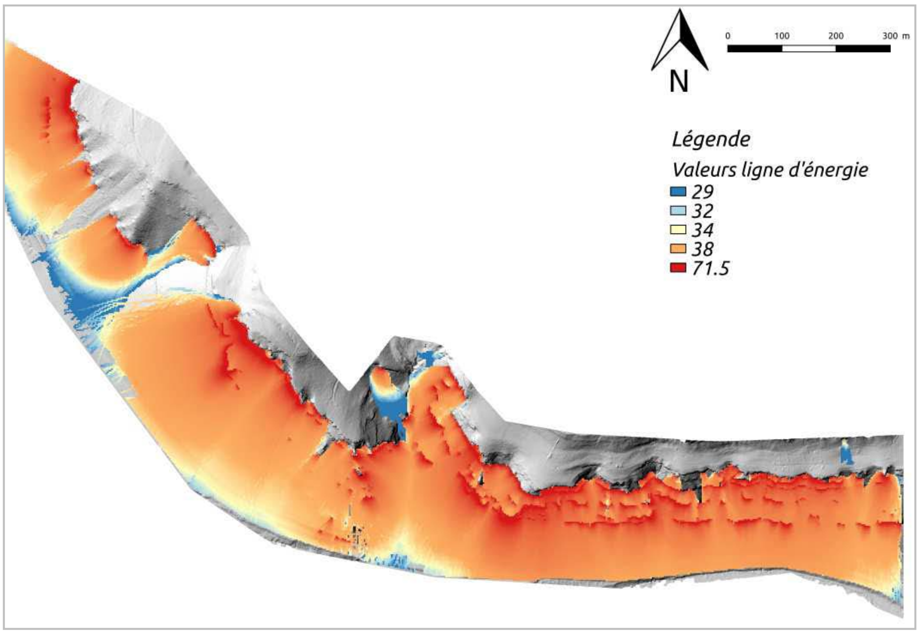



**Figure 4 -** Areas potentially affected by the rockfall hazard of the case study as a function of the energy line value β.

The map of areas potentially affected by the hazard shows that no point on the road can be considered as totally safe. All potential starting points were considered on topographic criteria only. The stability of the rocky compartments is not considered at all in this analysis.

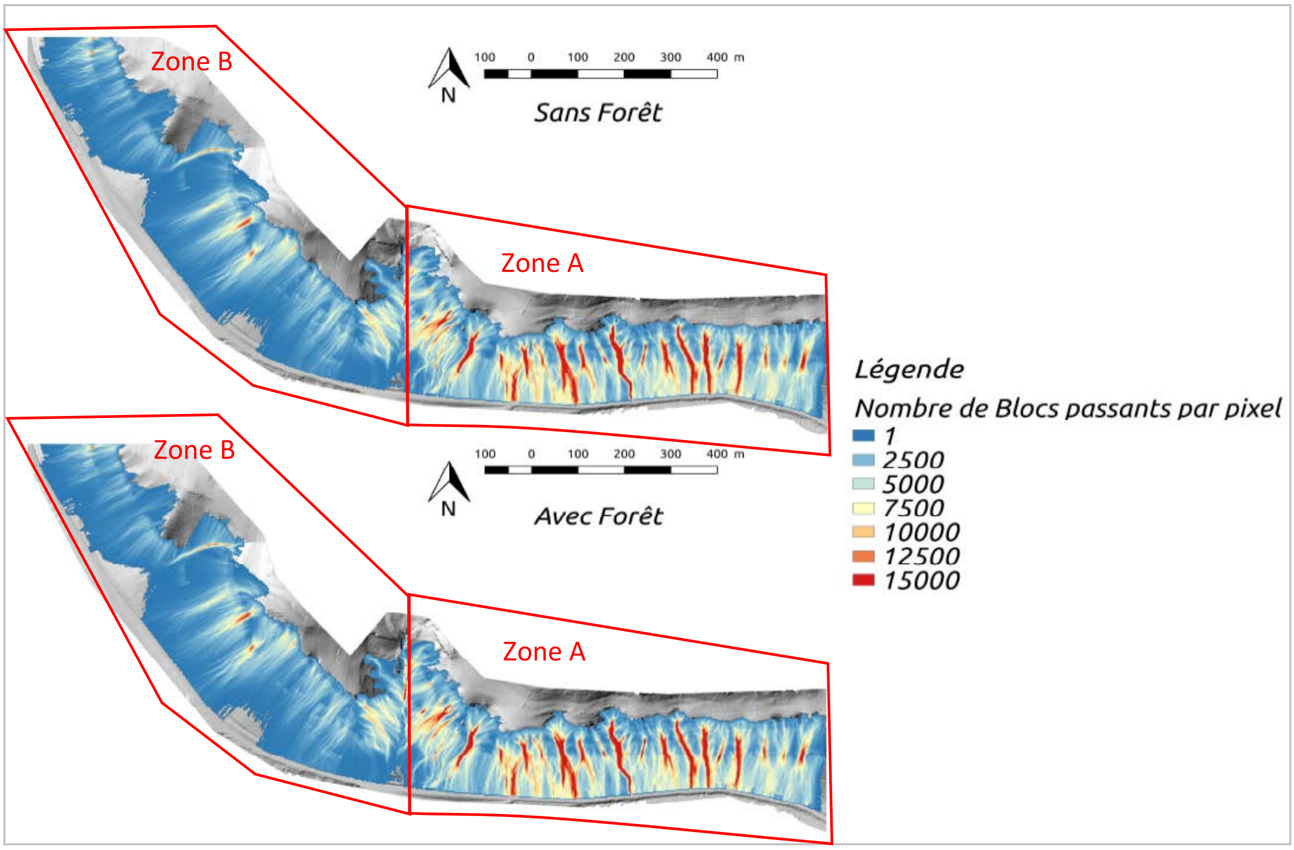



**Figure 5 -** Mapping of block propagation (number of blocks passing) with and without consideration of the forest at the case scale.

Although trajectory simulations quantify only the propagation hazard, the observed difference between zone A and B has an impact on the overall rockfall hazard. Indeed, the global hazard can be considered as the product of the initial hazard by the propagation hazard. In zone A, not only the propagation hazard is higher than in zone B, but the initial hazard is also higher because field surveys have shown a much larger number of blocks at the bottom of zone A than in zone B. These results show that it is not necessary to carry out a more detailed study on zone B because, since this sector is little exposed to the risk of falling blocks, the analysis of the forest protection function is not essential. As a result, the detailed analysis of simulation results was only performed on zone A.

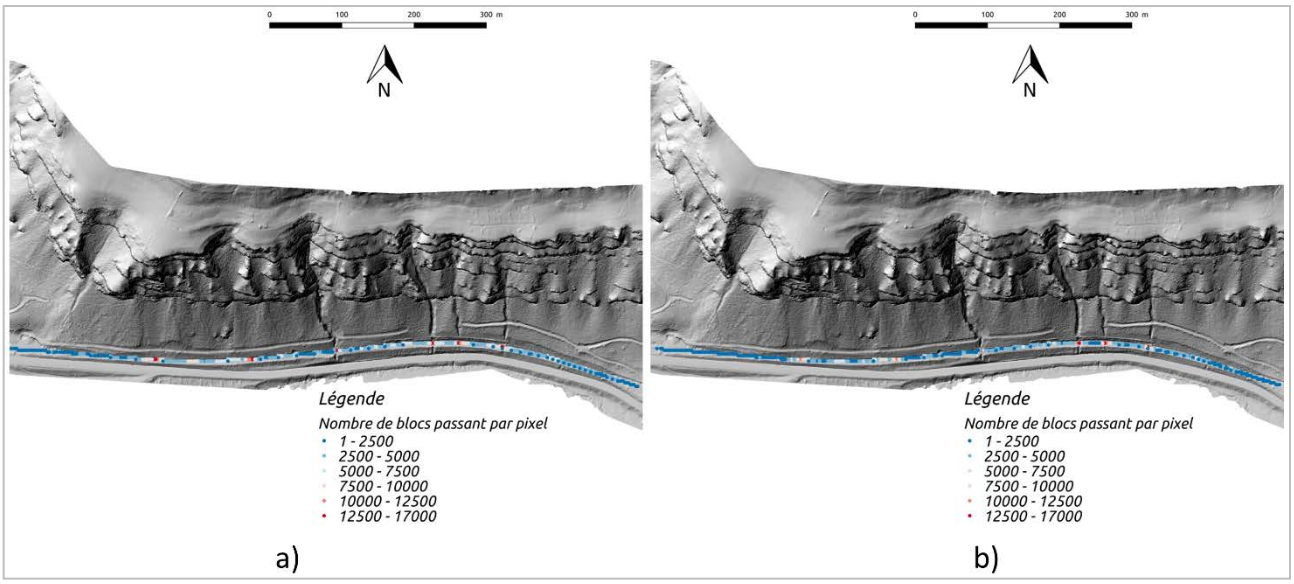



**Figure 6 -** Mapping of the number of blocks passing by cell at the level of the railway on zone A without (a) and with (b) considering the forest.

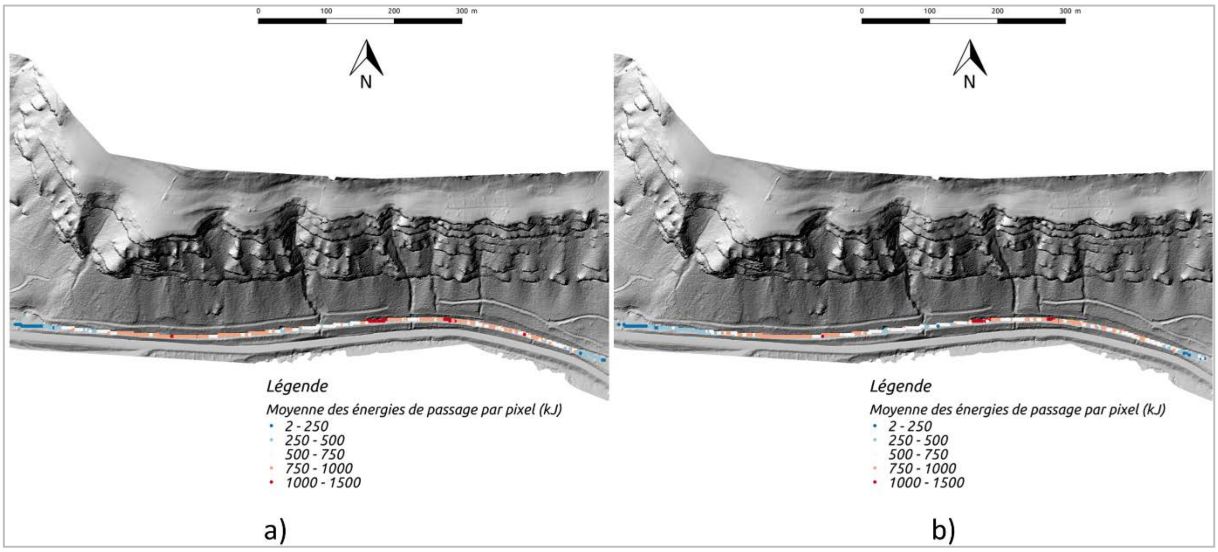



**Figure 7 -** Mapping of the average energies of blocks passing through each cell at the level of the railway on zone A without (a) and with (b) considering the forest.

The comparison of the results obtained, with and without forest, shows the significant contribution of the forest in reducing the number of blocks passing and their energy. This reduction is generally of the order of 1,000 passing blocks. It can reach 5,000 blocks locally. This reduction represents a significant percentage of reduction in the frequency of the propagation hazard.

However, the reduction of the average energy of the passing blocks is small compared with the maximal energies of the blocks (about 4,000 kJ). This average reduction is generally of about 100 kJ to 300 kJ.

Following these events, preconisation for works has been recommended ignoring the protection service provided by the forest:

- implementation of a deformable screen of category 8 (norm NFP 95-308) on a length of 250 m in zone A: € 200,000;
- implementation of a deformable screen of category 7 (norm NFP 95-308) on a length of 1,850 m for the rest of the area (zone A and B): € 1,110,000.

The length of road at stake in zone A (the case study) is of 880 m. Thus, the total investment cost of the proposed protective structure is € 578,000.

## *4.* ECONOMIC EVALUATION

- Selected economic approach:

the selected approach is the **RCM**.

- Selected time period for the evaluation*:*

the timespan of the assessment is **25 years**.

- Exposed assets:

the only asset exposed to the rockfall is a portion of the road **RD457** (880 m). The average annual daily traffic is of about 14,570 vehicles. At the level of the study area, if the road is closed because of a massive rockfall, reasonable alternative routes are possible, with an additional circulation time of about 13 minutes by the south and 15 minutes by the north. An additional time due to congestion must be expected.


**Figure 8 -** View of the asset at stake – Road RD437 at the bottom of zone A.

- Protection forests:

the forest stand is an **old mixed broadleaves coppice**. The basal area varies from 18 mq/ha (average tree diameter of 15 cm and a stem density of 1,019 stem/ha) up to 30 mq/ha (average tree diameter of 18 cm and a stem density of 1,179 stem/ha). The main tree species are *Quercus pubescens* Willd.*, Fagus sylvatica* L.*, Carpinus betulus* L.*, Fraxinus excelsior* L.*, Acer pseudoplatanus* L..

The forest offering a protection service reduces significantly the number of blocks passing (reduction of 40 % of the frequency) but it is less efficient in reducing the energy of blocks passing through. The kinetic energy developed by the falling block having the 95° percentile of the diameter measured in the area (about 1.5 mc) is reduced of only 20 % as shown in the following table.

- Forest effectiveness against rockfall:

| Asset | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| Road RD437 | 800 | 1,000 | 0.90 |

- Desired protection level from stakeholders:

stakeholders desire a high level of protection because the rock falls threaten one of the primary roads for the territory, but alternative itineraries can be easily used in case of closure of the road. The minimal level of protection desired by stakeholders is **75 % to 95 %**. The ideal protection level desired by stakeholders is 95 % to 99 %.

In the ASFORSEE model, the input data “Desired Protection Level from Stakeholders” is set at **95 %**.

- Score of the protection demand survey:

the survey has been filled by a manager of the road department within the general council of the Doubs sub-region. The score obtained is **20**.

5. **FOREST MANAGEMENT**

There is **no forest management** in the current situation.

6. **RESULTS**

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | 4,404,502 |
| **Overall discounted building cost with forest [€]** | 2,404,856 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

*- Monetary Protection Value* ***520,200 €***

*- Unitary Protection Value* ***28,900 €/ha***

*- Yearly Protection Value* ***902 €/ha/y***

7. **CRITICAL ANALYSIS OF RESULTS**

The level of protection offered by the forest in its current state is far from enough and can’t be used for building up an effective safety strategy based on the forest management. As the stakeholders and decision makers want to increase the level of protection, then the only adapted option for this site is to Invest in a 100 % engineering solution, which is very efficient but expensive. This conclusion is coming from the fact that if the current forest can significantly reduce the number of passing projectiles, it’s not the case about the energy reduction of the projectiles able to reach the road. With a potential reaching kinetic energy value of 800 kJ considering the current forest, a mixed engineering-natural solution using rockfall nets fixed on trees is not possible.

The protection value provided by the model correspond to the forest at its current state and does not consider the possible improvement of the protection service that can be reach by implementing a specific forest management. Aspects to analyze and consider for the future development of the model are:

- how to integrate the potential evolution and consequences of adapted forest management into the reduction of maintenance costs of the engineering solution;
- how adapted forest management can allow for the future replacement of rockfall nets to be installed on site.

| Case study name: | *Auronzo di Cadore, Italy* |
|---|---|
| **Responsible partner:** | *TESAF* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of Auronzo di Cadore.


**Figure 7 -** Municipal boundaries of Auronzo di Cadore.

## 2. CASE STUDY DESCRIPTION

The selected site is situated in the municipality of Auronzo di Cadore (BL) on the south-eastern face of mount Col di Vezza. The elevation ranges between 1,015 and 1,305 m a.s.l. and it is characterized by a typical Alpine climate, with a mean annual temperature of 7.2° C and an average annual rainfall of 1,212 mm.
The forest in the study site can be differentiated in two main typologies: in the lowest part the main species is *Picea abies* L. classified as a productive stand, while in the upper zone the main species is *Pinus sylvestris* L. and the stand is classified with a protective function.

## 3. CASE STUDY FEATURES

N/A

## 4. ECONOMIC EVALUATION

- Selected economic approach:

the **RCM**, the choice fell on this method because there are no rockfall protection nets *in situ*.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project.

- Exposed assets:

a **high voltage line** for 460 m and an 800 m stretch of **road SR48**.

- Protection forests:

a **pine forest** (*Pinus sylvestris* L.) in the upper zone and a **spruce forest** (*Picea abies* L.) in the lowest part classified as a productive stand.

- Forest effectiveness against rockfall:

| Assets | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| High voltage line | 530.4 | 624.1 | 0.99 |
| Road SR48 | - | - | 0.99 |

- Desired protection level from stakeholders:

stakeholders desire a high level of protection because the rock falls threaten a primary road for the territory. The level of protection desired by stakeholders is **75 %.**

- Score of the protection demand survey:

N/A

## *5.* FOREST MANAGEMENT

N/A

## *6.* RESULTS

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | 2,142,546 |
| **Overall discounted building cost with forest [€]** | 638,190 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***2,121,121 €***
- *Unitary Protection Value* ***105,006 €/ha***
- *Yearly Protection Value* ***3,278 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

The results obtained differ from those in the literature (see Discussion and Conclusions). The main attributable cause is the lack of input data.

| Case study name: | *San Vito di Cadore, Italy* |
|---|---|
| **Responsible partner:** | *TESAF* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of San Vito di Cadore.


**Figure 8 -** Municipal boundaries of San Vito di Cadore.

## *2.* CASE STUDY DESCRIPTION

The selected stand starts at an elevation of 1,120 m a.s.l. and it stops where the scree slope starts, at an elevation of 1,350 m a.s.l.. The area has a typical Alpine climate, characterized by cold dry winters and relatively warm and humid summers.

The forest is mainly composed by *Pinus sylvestris* L., with an important presence of *Picea abies* L. at the bottom. The site is defined as "typical mesalpic Scots pine stand" in the upper part, while at the bottom is defined as "mesalpic Scots pine stand". Furthermore, at the beginning of the scree slope there is a little stand of *Pinus mugo* Turra defined as "mesothermic Stone pine stand".

## *3.* CASE STUDY FEATURES

N/A

## *4.* ECONOMIC EVALUATION

- Selected economic approach:

the **RCM**, the choice fell on this method because there are no rockfall protection nets *in situ*.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project.

- Exposed assets:

Three stretch of a **road** are exposed. In particular, a 240 m stretch in the first part, a 450 m stretch in the second part e finally a 540 m stretch in the last part.

- Protection forests:

A **pine forest** with an important presence of *Picea abies* L. at the bottom.

- Forest effectiveness against rockfall:

| Asset | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| A | 360 | 399,3 | 0.92 |
| B | - | - | 0.99 |
| C | - | - | 0.99 |

- Desired protection level from stakeholders:

stakeholders desire a low level of protection, that is **25 %.**

Score of the protection demand survey:

N/A

## *5.* FOREST MANAGEMENT

N/A

## *6.* RESULTS

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | 460,778 |
| **Overall discounted building cost with forest [€]** | 275,835 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

*- Monetary Protection Value* ***423,455 €***

*- Unitary Protection Value* ***25,617 €/ha***

*- Yearly Protection Value* ***800 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

The results obtained slightly differ from those in the literature (see Discussion and Conclusions), as shown in the Auronzo di Cadore case study. The main attributable cause is the lack of forest management costs that lower the value of the protective service, bringing it back into the range of values present in the literature.

| | |
|---|---|
| **Case study name:** | *Strailach, Germany* |
| **Responsible partner:** | *BLW* |

*1.* **GEOGRAPHICAL FRAMEWORK**


**Figure 1 -** Localization of Strailach.

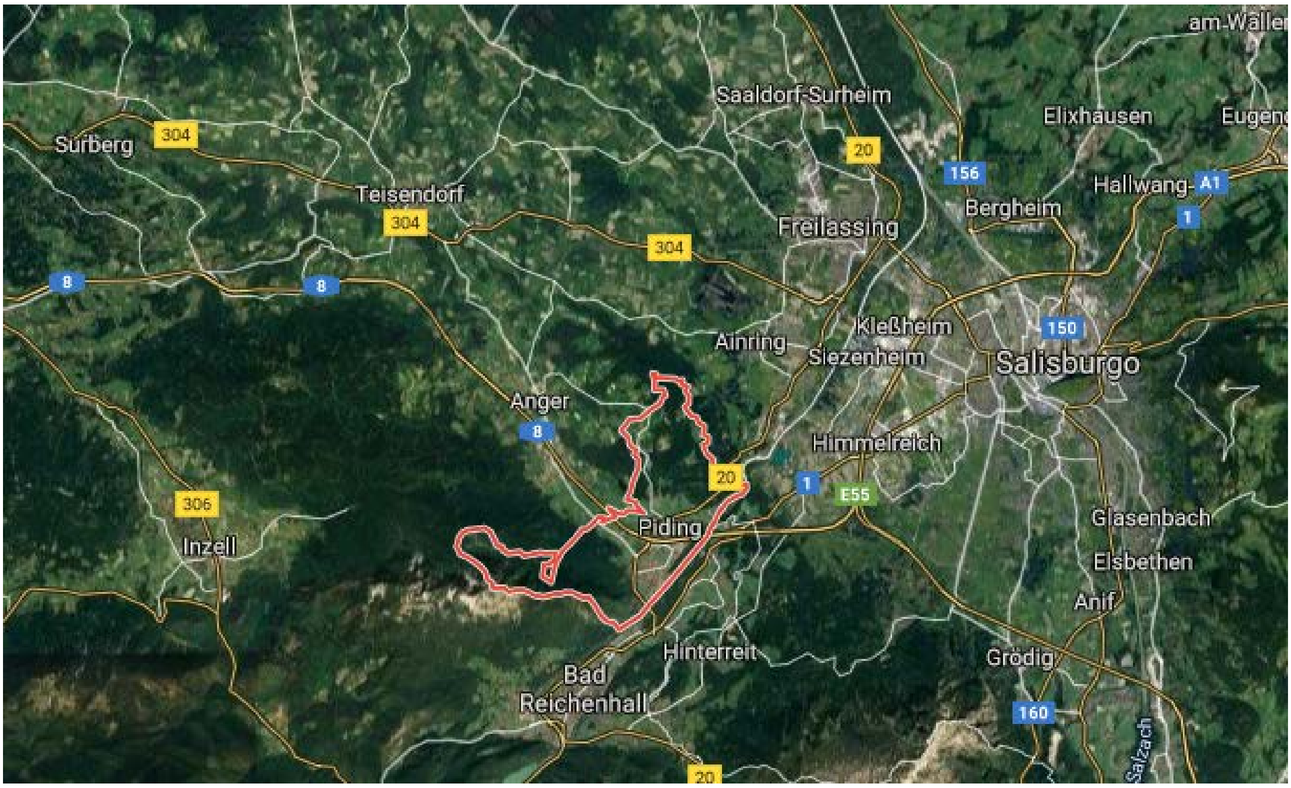



**Figure 9 -** Municipal boundaries of Piding.

## 2. CASE STUDY DESCRIPTION

The area of interest is located near the village of Piding, at an altitude of approximately 455 m above sea level, in the south-eastern part of Germany, on the border with Austria, specifically in the Land of Bavaria (47° 46′ N, 12° 55′ E).

Piding hosts a population of about 5,491 inhabitants (as of 30 July 2018) on an area of 17.67 km$^2$ (Berchtesgadener Land, 2018). The total area consists of 56.2 % forest (993 ha), 25.7 % agricultural land (454 ha), 12.8 % urban areas (226 ha), 3.3 % other land, e.g. rocks (59 ha) and 2 % water (35 ha).

## 3. CASE STUDY FEATURES

Figure 3 delimits the boundaries of the protection forest in the regional technical map (3a), the ortophoto (3b) and the DTM (Digital Terrain Model - 3c).

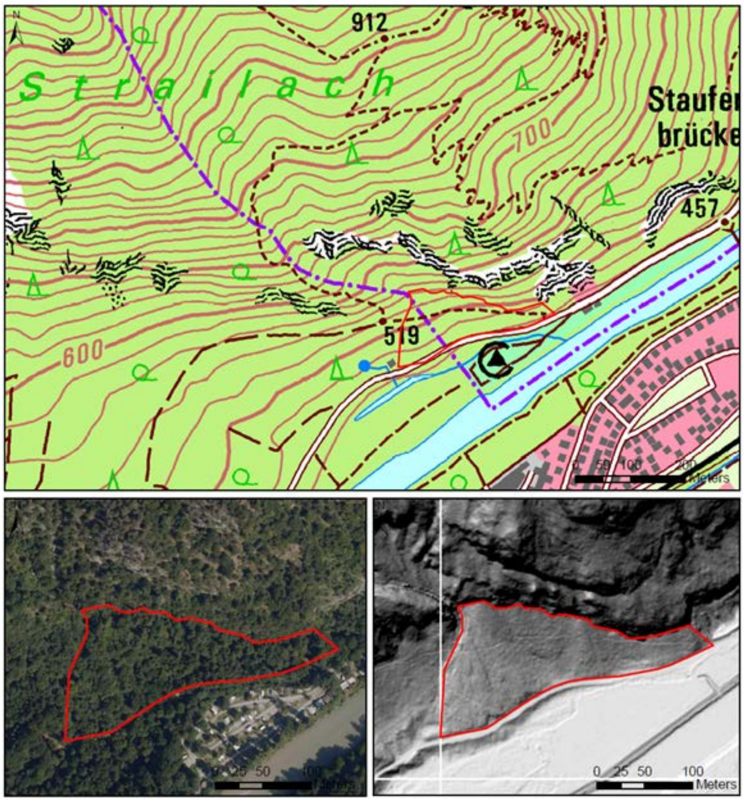



**Figure 3 –** Case study.

## 4. ECONOMIC EVALUATION

- Selected economic approach:

the **RCM** is adopted because the rockfall nets were installed to protect a forest road, frequently used for recreational activities and a campground.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project.

- Exposed assets:

the only exposed element is a 307 m stretch of **forest road**, frequently used for camping and recreational activities.

- Protection forests:

the forest structure is comparably complex with partly dense shrub vegetation composed of *Corylus avellana* L..

- Forest effectiveness against rockfall:

| **Asset** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Forest road | 527.1 | 529.1 | 0.273 |

- Desired protection level from stakeholders:

stakeholders desire a medium because the event threatens a road of secondary importance, moreover the kinetic energy released by the boulder is not high, therefore there is not even damage to the roadbed, also due to the small size of the falling boulders (95° percentile). The level of protection desired by stakeholders is **50 %.**

- Score of the protection demand survey:

the score is **21 points**. From a qualitative point of view, the stakeholder directly involved, a federal administrator, was particularly sensitive to the protection of the area, so the score obtained made it possible to increase the desired level of protection to a higher class, **from medium (50 %) to high (75 %)**.

## *5.* FOREST MANAGEMENT

There are **no forest plans** available and the absence of data did not allow ASFORESEE to calculate this item, so the value within it is 0 €.

## *6.* RESULTS

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | 2,079,421 |
| **Overall discounted building cost with forest [€]** | 1,244,801.25 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***0 €***
- *Unitary Protection Value* ***0 €/ha***
- *Yearly Protection Value* ***0 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

The result obtained is 0 € because the forest does not play an effective role against rockfall. Therefore, its value is equal only to the expenses of forest management, which, not being present in this case, attribute a zero value to the protective service.

| Case study name: | *Podbrdo, Slovenia* |
|---|---|
| **Responsible partner:** | *SFI* |

## *1.* GEOGRAPHICAL FRAMEWORK

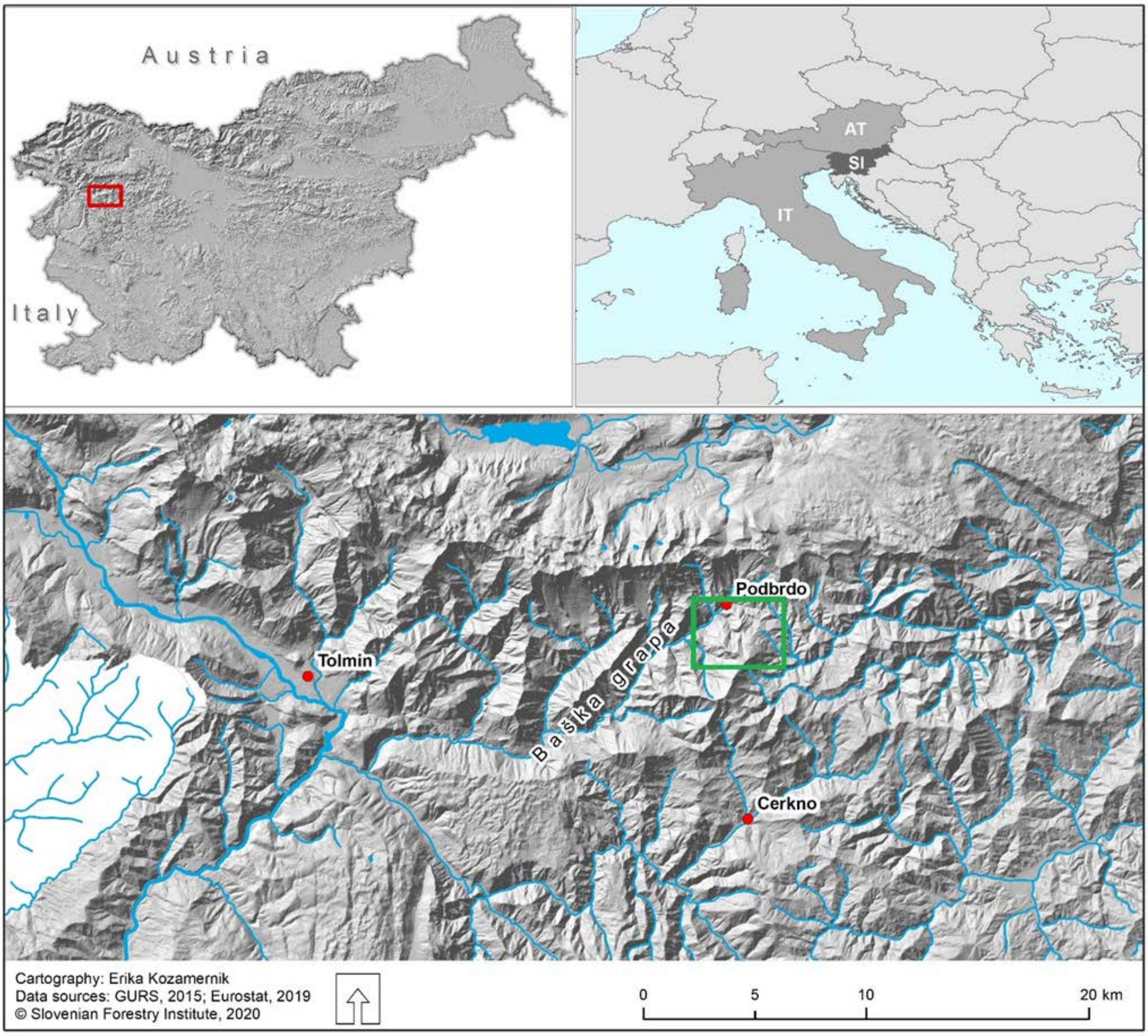



**Figure 1 -** A coarse scale geographical representation of a location (red rectangular) of a wider case study area and a finer scale representation of the wider area and actual location of the case study area (green rectangular).

## *2.* CASE STUDY DESCRIPTION

Slovenian case study is located in the north-western part of Slovenia more detailed in the upper (north-east) part of the Baška grapa valley, near the town of Podbrdo (Figure 1). Baška grapa is about 30 km long valley of the river Bača, which in the upper part flows in the northeast-southwest direction, and in the south part in the east-west direction. The surrounding mountains do not exceed 2,000 m, but the world is very diverse due to the numerous narrows, limestone-carved side gorges. Images below indicate the wider and more detail location of the case study area.

The study area is 160.8 ha large and is almost entirely forested (95 % or 152.5 ha) (Figure 2). The rest is agricultural land and some infrastructure. More than half (53 %) of the area is occupied by old growth forest stands and an additional 23 % with stands in regeneration, where both sum up to a bit more than three quarters. The average stem diameter of 33 cm and growing stock is above nations average at 427 $m^3$/ha y. Average number (modelled) of trees per hectare is 365.


**Figure 2 -** A digital ortho-photo image of the case study area.

The bottom part of the area reaches to the railway which connect the village Bohinjska Bistrica on one side and Most na Soči on the other. Train traffic is rare, however mostly used by car shuttle train and occasional cargo and also as public transport (personal trains) (Figure 3). It was built in 1906 and significantly renovated in the 60s, however it is still not electrified, relatively steep in the section between Podbrdo and Grahovo pri Bači and thus expensive to run. The traffic increases significantly in the summertime when 'historical' trains runs daily carrying tourists and railroad enthusiasts. It breaches the river of Bača seven times during its course through the narrow valley of Baška grapa but keeps predominantly under the north-facing slopes while the road runs almost entirely on the opposite side of the valley. Next to the railway a regional road, one of few connecting Gorenjska region with the upper Primorska region (NW part of Slovenia) is also in near proximity of the case study forest area (Figure 4). The road is important in terms of traffic density as well with app. 1,000 vehicles passing daily.

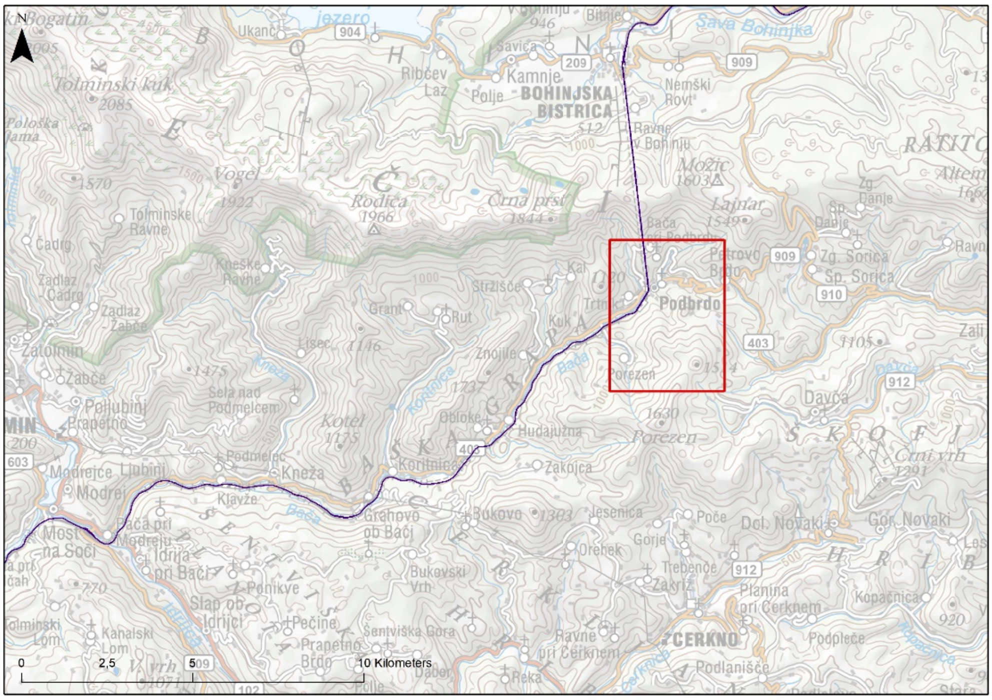



**Figure 3 -** The railroad from Bohinjska Bistrica to Most na Soči (north-western part of Slovenia), with a more detailed location of a case study area (red square).

**Figure 4 -** A photo of the train rail in Baška grapa.

### 3. CASE STUDY FEATURES

From the detailed digital terrain model, it is possible to see that the slope faces mainly in the directions north to north-west with two larger gullies having outsets in the south and east, merging close to the central part and then continuing as a larger trench in a north-west direction (Figure 5).

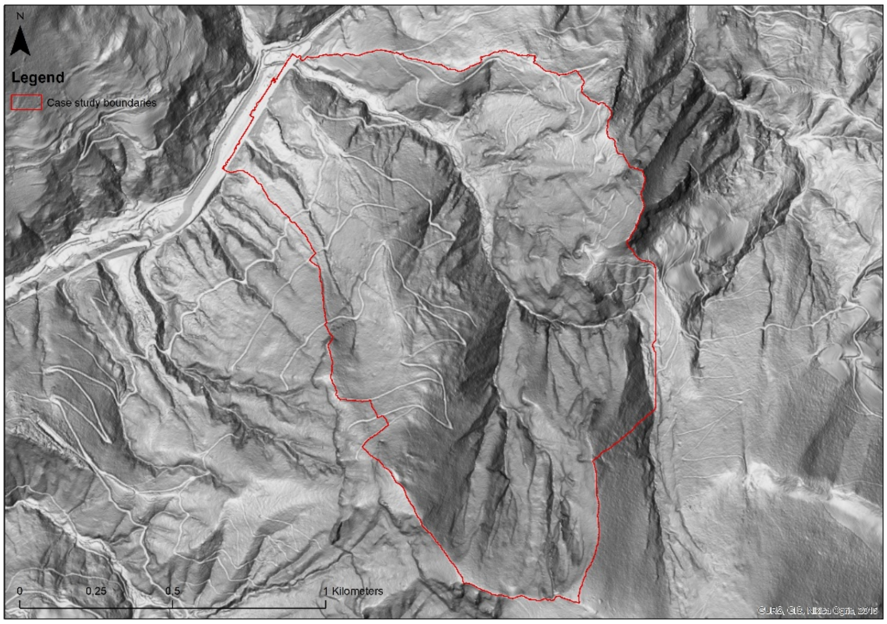



**Figure 5 -** Digital elevation model of the case study area.

Due to significant inclination of terrain and geological structure – marl and sandstone with inclusions of limestone –, which is susceptible to erosion, rockfall is quite frequent, which poses threat to rail traffic. Several defensive facilities were built in the past, however not on all locations needed. In fact, no protection infrastructure is in place above the railroad in this part of the case study area, thus all protection currently available is provided by the forests uphill. The total length of the railroad bordering the forest area is 430 m.

Implementation of Rockyfor3D model garnered modelled rockfall sources, which are indicated in red on the image below (Figure 6). Concentration of sources is in the eastern part of the area also due to steeper terrain.

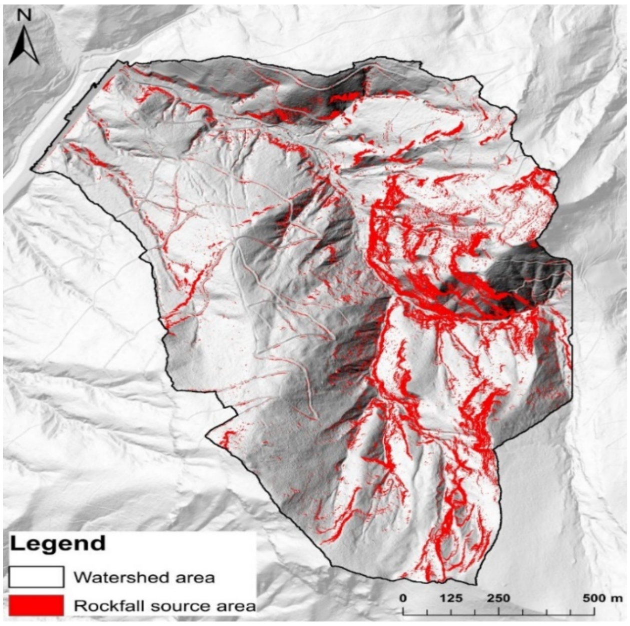


**Figure 6 -** Rockfall sources as modelled by Rockyfor3D.

The most distant point of rockfall source is more than 2 km from the railroad uphill, which means that travel lengths of rocks are relatively long in this forest area indicating potentially high protection capacity. There was no empirical field data on either frequency or mass of past rockfall events to calibrate the model, however forest inventory data on forest stands were used:

- mean DBH (forest stand level data on representation of development phases recalculated as an area-weighted average for entire watershed);
- number of trees (by using local yield tables and an equation N_trees=104,449* 〖DBH〗 ^(-1,595); see graph below) (Figure 7);
- percentage of conifers in the growing stock (using forest management inventory data).

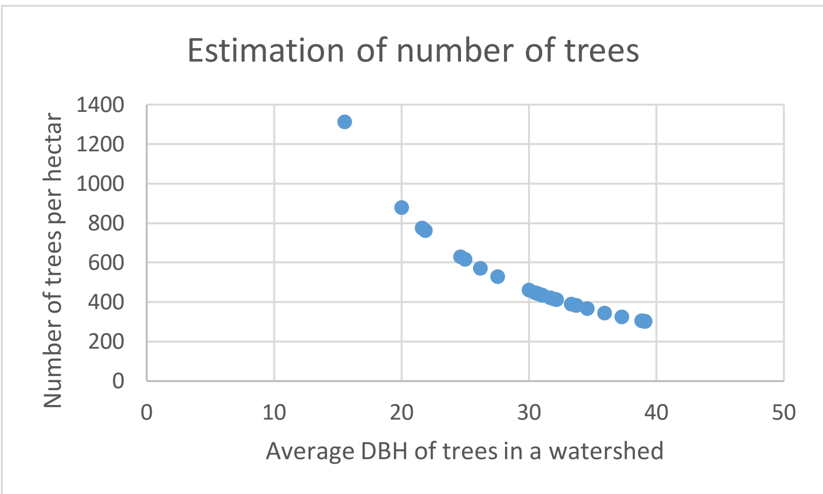


**Figure 7 -** Model estimation of the number of trees per hectare in a watershed based on the average DBH of trees.

4. **ECONOMIC EVALUATION**

- Selected economic approach:

the **RCM** is adopted because the rockfall nets were installed to protect a railroad, frequently used.

- Selected time period for the evaluation*:*

**10 years**. The time horizon fits the one established within system of forest management planning in Slovenia as all management plans have the same period of validity.

- Exposed assets:

the asset which is exposed to rockfall is a **railroad** connecting Bohinjska Bistrica and Most na Soči, but the case study is focused on a specific section stretching through the narrow valley Baška grapa, with step north to north-west facing steep forested slopes.

- Protection forests:

the forest area under investigation is the first one after the railroad exits the tunnel going under Kobla mountain (Karavanke Alps).

- Forest effectiveness against rockfall:

| **Asset** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Forest road | 4,152 | 5,744 | 0.35 |

- Desired protection level from stakeholders:

was set on **80 %** indicating relatively **high demand**. Given the ORPI of 0.35, the protection is still not sufficient.

- Score of the protection demand survey:

the score of protection survey **has not been completed** thus only the abovementioned value was used.

5. **FOREST MANAGEMENT**

Forests in case study area are managed according to forest management plan (author Slovenian Forestry Service) for forest management unit Baška grapa with a period of validity 2016-2025. A short summary of the plan reveals that forests in this area hold above country's average growing stock of 352 $m^3$/ha, with a below average increment of 6.5 $m^3$/ha y. The latest indicates that the forests are mainly growing on poor soils and in extreme relief conditions. European beech dominates with 60 % of overall growing stock, followed by Norway spruce (13 %), European hop-hornbeam (7 %), and other species being represented by less than five percent each. Harvesting rate is set relatively high (101 % of yearly increment) due to large need to establish young growth – more than half of the 686,077 m$^3$ of projected fellings are planned as regeneration cuttings of mature forest stands, which represent almost half of entire forest area. Soto say, age distribution in Baška grapa forest management unit is unbalanced with a serious overrepresentation (45 %) of mature forests and a strong lack of young growth (1.3 %). The value of forest management amounts to **240,349 €**.

## *6.* RESULTS

| | |
|---|---|
| **Overall discounted building cost without forest [€]** | - |
| **Overall discounted building cost with forest [€]** | - |
| **Overall discounted stumpage value [€]** | 240,349 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***240,349 €***
- *Unitary Protection Value* ***1,495 €/ha***
- *Yearly Protection Value* ***137 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

Since kinetic energy reduction due to forest being present is notable, however not sufficient to reduce the need for extensive protection, facilities costs for such infrastructure are high in both cases – with and without forests. The ASFORESEE module of 'defensive facility' predict the same protection net characteristics due to SEL kinetic energy exceeding the max absorbable energy of 10,000 kJ (19,902 kJ in case without forest and 14,386 kJ with forest). In this case the discounted stumpage value (the net cost/benefits of forest management) actually increases the value of forests.

Overall, such estimates would be a novelty in case of forest management in Slovenia as economic valuation of protection capacity of forest is not practically implemented except in a few ad-hoc project researches studies. It would enrich information evidence for forest managers to effectively earmark limited resources for supporting such functions of forest stands. Up to now, forest management planning is considering a wide variety of positive effects of forests on wellbeing in terms of forest function mapping and adapting management accordingly, however criteria upon which this is done are ambiguous and to some extent arbitrary. In majority of cases of forest functions, the system lacks solid data on which designation of a specific forest area to provide for a specific function would be professionally valid. The designation is commonly based on visual assessment of forest stands and environmental circumstances and ignores the true preferences of local people. Economic valuation approach implemented in RockTheAlps integrates the aspect of societal demand for protection via the required level of protection and so guarantees this missing element. It also introduces and approach which is transparent, repetitive and enables sensitivity analysis. The latter enables forest managers to pinpoint the structure of forest stand, which provides protection but can also be optimized in a cost benefit technique.

Future work in this respect would be to investigate possibilities for introducing this approach into forest management in Slovenia. On-going process of renovation of the system of planning might be a suitable opportunity in which the deliverable D.T4.5.1 would for sure be a useful input and a starting point.

| | |
|---|---|
| **Case study name:** | *Cesana Torinese, Italy* |
| **Responsible partner:** | *DISAFA* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of Cesana Torinese.

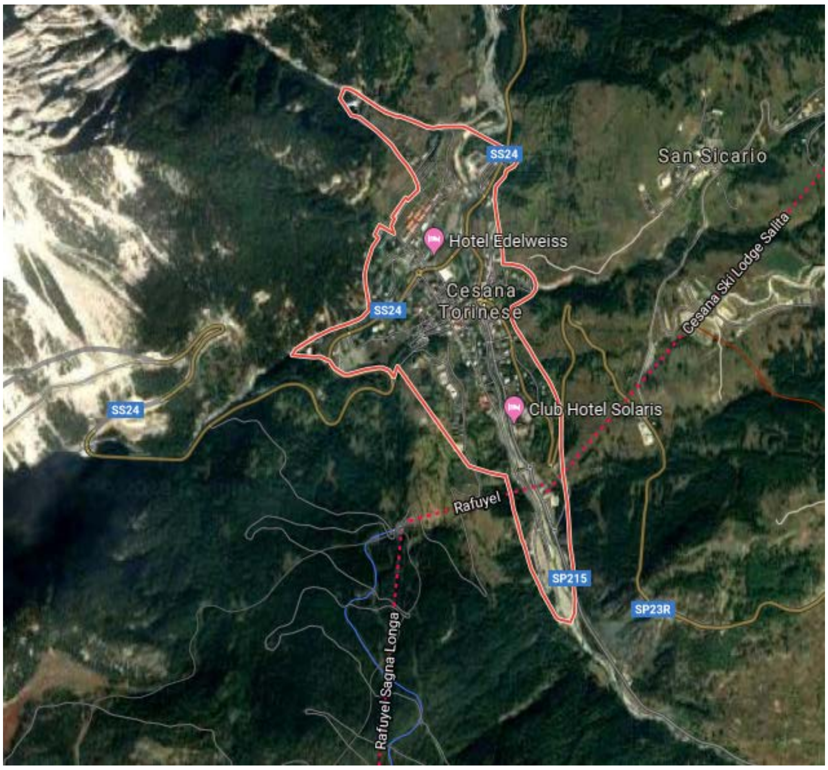



**Figure 10 -** Municipal boundaries of Cesana Torinese.

## 2. CASE STUDY DESCRIPTION

The area of interest is located 3 km from the town of Cesana Torinese, at an altitude from 1,300 to 1,600 m above sea level in Val di Susa, on the border with France (44° 57′ 11'' N, 6° 47′ 30'' E).

Cesana Torinese hosts a population of about 1,000 inhabitants (as at 31 December 2014) on a territory of 121 $km^2$ (Consorzio Forestale Alta Valle Susa 2000; Comune di Cesana Torinese 2014). The total area is made up of 40.2 % of forests (4,861 ha), 36.8 % of meadows and grassland (4,449 ha), 1.6 % of urban areas (infrastructures and buildings) (192 ha) and 21.5 % of other land, e.g. bushes (2,597 ha).

## 3. CASE STUDY FEATURES

Figures 3 and 4 show, respectively, the boundaries of the protection forest (red polygon) and the element to be protected (i.e., road SS24). A dual carriageway road, busy 365 days a year and leading to the French-Italian border.


**Figure 11 –** Localization of the case study.


**Figure 4 -** View of the asset at stake – Road SS24.

4. **ECONOMIC EVALUATION**

- Selected economic approach:

the **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the vulnerable element is of some importance.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project, influenced by the duration of the silvicultural interventions.

- Exposed assets:

the only exposed asset is a 500 m stretch of **road SS24**, very busy and located on the border between Italy and France.

- Protection forests:

a **larch forest** of 120 mc/ha of commission, with an increase of 0.5 mc/ha/year. Carried out a cut in 2007 of about 1.5 ha with a harvest intensity of 25 %, cycle duration of the cuts 25 years.

- Forest effectiveness against rockfall:

| **Asset** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Road SS24 | 520 | 530 | 0.860 |

- Value of the exposed assets:

road data obtained from the Piedmont Region pricelist (2019), movable property and value of human life defined according to what reported by the ERSAF/ETIFOR project partners, presence of car from average annual daily traffic card (ANAS, 2017).

| **Asset** | **Unitary value immovable [€/m]** | **Exposed area immovable [m]** | **Unitary value movable [€]** | **Presence probability movable [/h]** | **Presence probability people [/h]** |
|---|---|---|---|---|---|
| Road SS24 | 887.13 | 0 | 20,039 | 300.80 | 601.60 |

## *5.* **FOREST MANAGEMENT**

There are **no forest plans** available and the absence of data did not allow ASFORESEE to calculate this item, so the value within it is 0 €.

## *6.* **RESULTS**

| | |
|---|---|
| **Overall avoided damage [€]** | 125,162 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***125,162 €***
- *Unitary Protection Value* ***20,860 €/ha***
- *Yearly Protection Value* ***651 €/ha/y***

## *7.* **CRITICAL ANALYSIS OF RESULTS**

The results obtained differ from those in the literature (see section Discussion and Conclusions). The main attributable causes are:

▪ the value of vulnerable elements: in the case studies present in the literature, higher unit values are assumed than those adopted for Cesana Torinese;

▪ the number of vulnerable elements: in the case study, reference is made only to a stretch of road. In the literature, instead, a greater number of elements at risk are considered.

| | |
|---|---|
| **Case study name:** | *Colcuc, Italy* |
| **Responsible partner:** | *TESAF* |

*1.* **GEOGRAPHICAL FRAMEWORK**


**Figure 1 -** Localization of Colcuc.

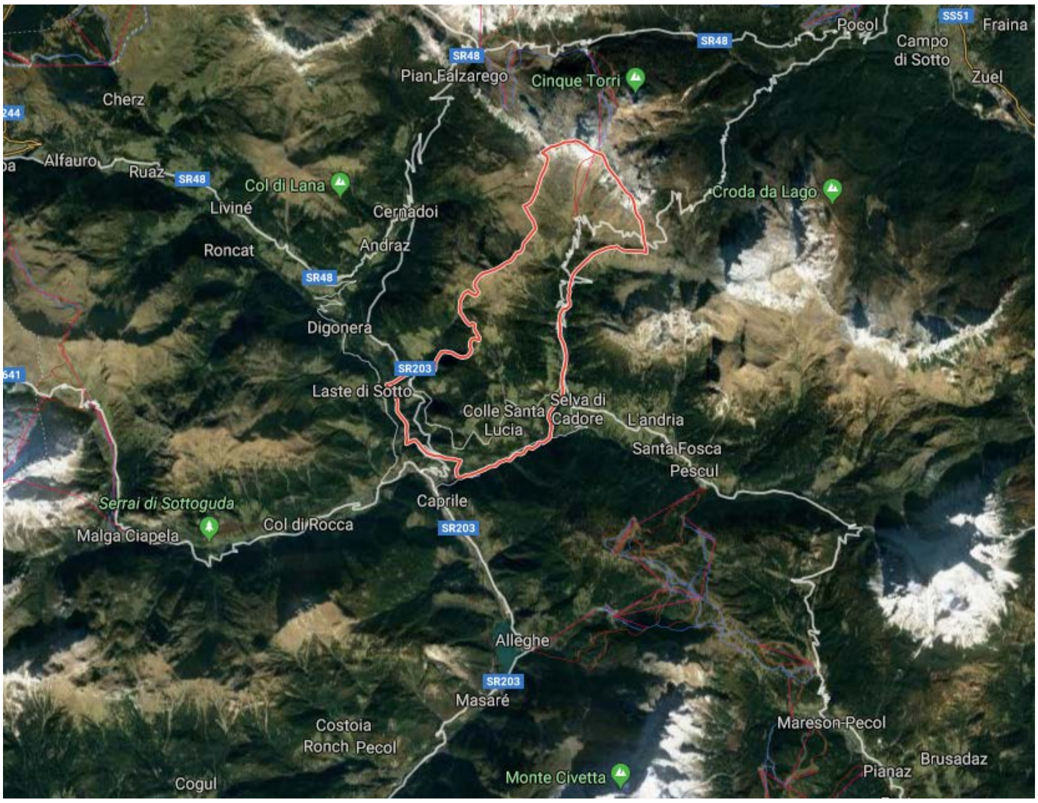



**Figure 12 -** Municipal boundaries of Colle Santa Lucia.

*2.* **CASE STUDY DESCRIPTION**

The case study is located on Monte Pore, close to Colcuc, municipality of Colle Santa Lucia (BL). The case is on the south western face of the mountain and it has an elevation that varies from 1,360 to 1,710 m a.s.l. The main forest species is *Picea abies* L., with sporadic presence of *Larix decidua* L. at the higher elevations. On the 2nd of April 2004 the site was affected by a massive landslide (around 4,000 mc of material) that defined the site as "active" for rockfall concern. The area is cut at different points along the study site by a hiking/biking trail, a local road and a regional road. After the mentioned event, some concrete infrastructures were built in order to minimize the risk to the stakeholders.

For the means of the research a transect has been created on the study site, it is located at 1,490 m a.s.l. and it is 20 m large and 160 m long, parallel to the level curves, it is 25 m downhill respect to the road that pass through the site.

**CASE STUDY FEATURES**

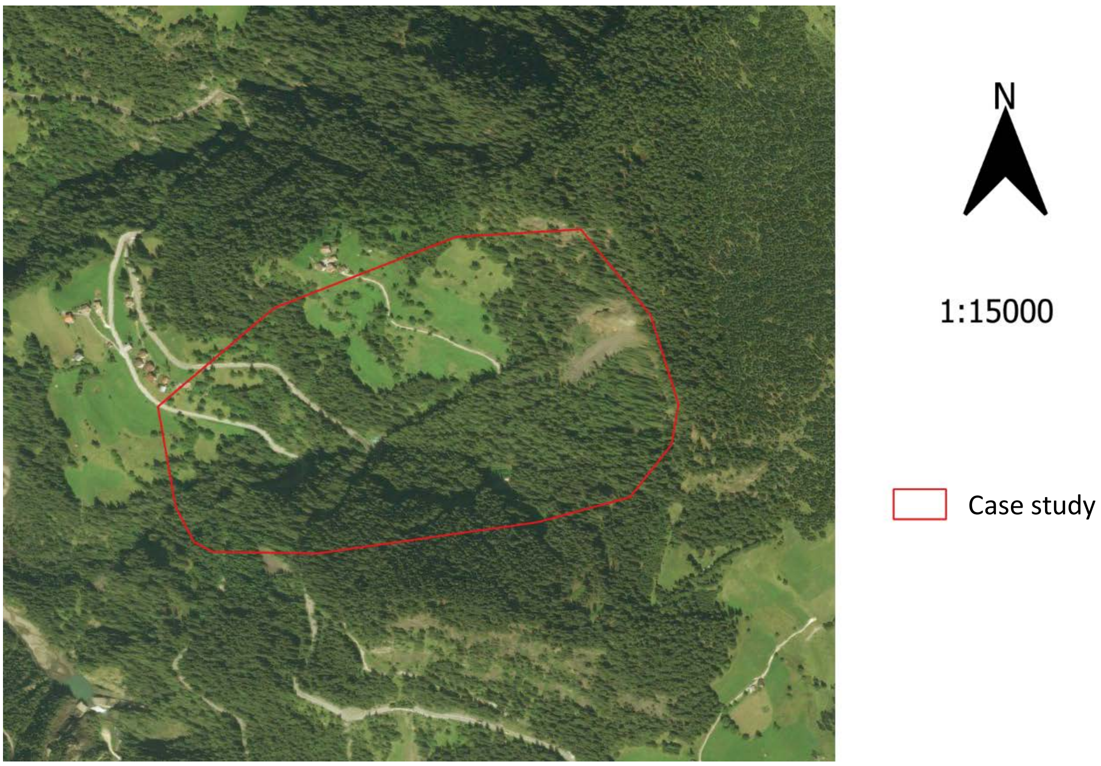



**Figure 13 –** Localization of the case study (ortophoto).

*3.* **ECONOMIC EVALUATION**

- Selected economic approach:

the **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the vulnerable element is of some importance.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project.

- Exposed assets:

a 512 m stretch of **mountain trail**, a 364 m stretch of **local road** and a 144 m stretch of **regional road**.

- Protection forests:

a **spruce forest**, with sporadic presence of *Larix decidua* L. at the higher elevations.

- Forest effectiveness against rockfall:

| Assets | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| Mountain trail | 1,319.30 | 1,421.30 | 0.42 |
| Local road | - | - | 0.75 |
| Regional road | - | - | 0.92 |

- Value of the exposed assets:

| Asset | Unitary value immovable [€/m] | Exposed area immovable [mq] | Unitary value movable [€] | Presence probability movable [/h] | Presence probability people [/h] |
|---|---|---|---|---|---|
| road | N/A | - | 20,039 | 4,2 | 8,4 |

4. **FOREST MANAGEMENT**

N/A

5. **RESULTS**

| | |
|---|---|
| **Overall avoided damage [€]** | **27,895** |
| **Overall discounted stumpage value [€]** | **0** |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

*- Monetary Protection Value* ***27,895 €***

*- Unitary Protection Value* ***2,273 €/ha***

*- Yearly Protection Value* ***71 €/ha/y***

6. **CRITICAL ANALYSIS OF RESULTS**

The results obtained differ from those in the literature (see Discussion and Conclusions) because there is the lack of input data.

| Case study name: | *Cevo, Italy* |
|---|---|
| **Responsible partner:** | *ERSAF (ETIFOR) - Simulations by UniMIB* |

1. **GEOGRAPHICAL FRAMEWORK**


**Figure 14 -** Localization of Cevo.


**Figure 15 -** Localization of the case study.

2. **CASE STUDY DESCRIPTION**

Cevo case study is in the Adamello Natural Park, within the Province of Brescia, Lombardy Region, between 600 and 950 m a.s.l..

It is a public owned forest area and its management plan is out of date (expired in 2014): the forest is not actively managed now, despite the presence of relatively valuable species as chestnuts groves.

There have been several rockfall events in the past years, the most recent ones have occurred in 2009 and 2017. The main structure at risk is the Provincial road that is located right underneath the site.

3. **CASE STUDY FEATURES**

Figure 3 shows the elements characterizing the case study: the protection forest (highlighted in grey) has been identified starting from the source area (highlighted in pink) and by considering and buffering the most probable rocks' paths. This also enlightened the asset to be protected that is the road located below the forest (highlighted in yellow).

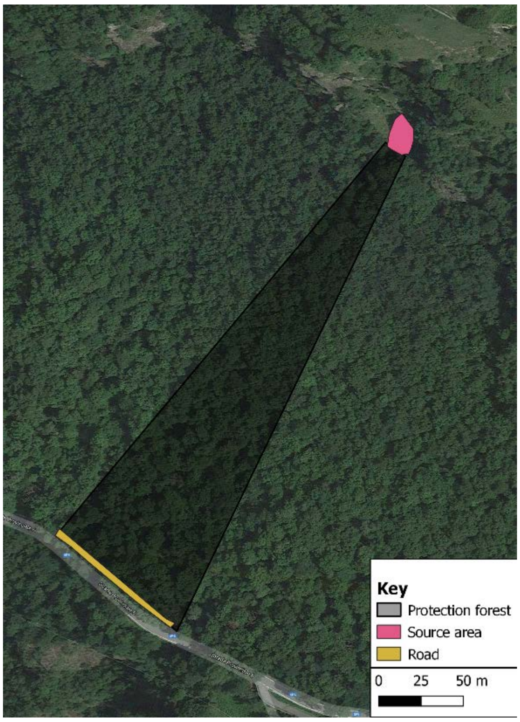



**Figure 3 -** Source area, protection forest and the asset to be protected (road).

4. **ECONOMIC EVALUATION**

- Selected economic approach:

we choose the **ADM** in order to implement an alternative/different approach to the RCM. In addition to this, in our opinion the ADM could be easily communicated to/understood by citizens and policy makers.

- Selected time period for the evaluation*:*

**25 years**, in order to be consistent with the other case studies addressed within the project.

- Exposed assets:

the only exposed asset is the **provincial road n. 6**, from Demo to Fresine, connecting the local villages to the main road (SS42). The road is at risk for a total length of 86 m. Other possible valuable assets in the area (high voltage lines, hydroelectric dam) are not reached/affected by rockfall events simulations.

- Protection forests:

although information about the forest status is not updated (forest management plan expired in 2014 and not updated), it can be described as an **irregular stand, mixing coppice forests** (chestnut, oak, hornbeam and manna ash), and **high forests** (chestnut and spruce). The total area covered by the protection forest is **3,58 ha**.

- Forest effectiveness against rockfall:

| **Asset** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Provincial road n. 6 | 0.472 | 79,655 | 0,994 |

the 95° percentile has been calculated from the dimensions of the boulders from previous events, showing a dimension of 1,07 mc. The efficiency simulations have been performed by Milano-Bicocca University team through the proprietary software HY-STONE.

- Value of the exposed assets:

| **Asset** | **Unitary value immovable [€/m]** | **Exposed area immovable [mq]** | **Unitary value movable [€]** | **Presence probability movable [/h]** | **Presence probability people [/h]** |
|---|---|---|---|---|---|
| Provincial road n. 6 | 156.99 | 12 | 20,039 | 40 | 80 |

- Unitary value immovable:

obtained from Lombardy Region, Regional pricelist of public works - ed. 2019 (i.e., the official pricelist for public works in Lombardy Region), by considering the expected damage a 1,07 mc rock could have on an asphalt road.

- Exposed area immovable:

the area that could be affected by the damage and therefore could need to be repaired.

- Unitary value movable:

obtained from Fleet&Mobility, Mercato Auto Valore - ed. 2017 (i.e., Car Market Value), where the average purchase value of a car in Italy is estimated to be **20,039 €**.

- Presence probability movable:

obtained as an expert-based estimation by interviewing a transport/logistic engineer (Ministero delle Infrastrutture e dei Trasporti, 2018), who compared the road being assessed with average data for mountain roads at the national scale.

- Presence probability people:

we estimated an average of **2 people** (i.e. 1 driver and 1 passenger) per car.

*5.* **FOREST MANAGEMENT**

The area is not managed, and there are **not planned interventions** that could affect forest value.

*6.* **RESULTS**

| **Overall avoided damage [€]** | 163,995 |
|---|---|
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

*- Monetary Protection Value* ***163,995 €***

*- Unitary Protection Value* ***45,761 €/ha***

*- Yearly Protection Value* ***1,429 €/ha/y***

*7.* **CRITICAL ANALYSIS OF RESULTS**

Some assumptions were necessary to perform the evaluation exercise:

- every rockfall event has the same dimension distribution;
- the expected rockfall causes the same damage as of similar past events;
- the number of car passages per day on the road equals the average value estimated for similar roads at the national level.

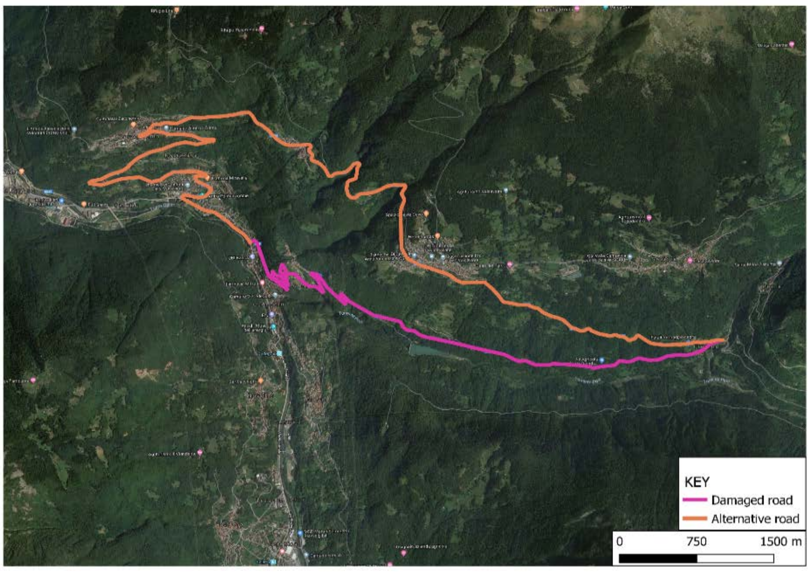
The evaluation exercise gives back some important information: the forest appears to provide fundamental protection to prevent damages to the asset, as its efficiency is estimated at 99.4 %. Considering the frequency of rockfall events in the area, the importance of the forest and of its management is unquestionable. While under current conditions there is limited room for increasing efficiency by reactivating active forest management it is possible (based on empirical evidence) that, in the long-term, missing management might lead to forest ageing and worsening of average conditions and this might ultimately turn into lower protection efficiency by the forest.

## *8.* ADDITIONAL EVALUATION

This section has been developed only for this case study, in agreement with ERSAF.

We have explored options to enrich the evaluation approach defined by the ASFORESEE model with additional components of the "avoided damage" value, namely indirect losses/damages caused by rock-fall events. By reviewing available scientific and grey literature on "avoided damage" we found that several additional components were considered in principle but rarely applied and computed in practice. Moreover, some of them that were estimated in some studies were not relevant for the addressed case study (e.g., avoided crop failure of agricultural areas - Barth & Döll, 2016). Business interruption and all the other losses associated to it are estimated to account for 50 % to 70 % of losses associated to hazards/extreme events (Allianz Risk Pulse, 2014). However, this is an average figure mainly derived for industrial activities that cannot compare with ordinary business activities carried out within the case study area. In a similar way, while it is well known that catastrophic events can cause effects also on unaffected economic sectors (so-called "ripple effect"), due to business relations, this echoing can hardly be estimated and accounted for. Besides this, an ordinary rock-fall event normally cannot be assumed as a catastrophic event.

Based on above-reported considerations, the only additional avoided damage component we can consider with a raw approach consists of the supplementary costs that car-drivers must bear in order to bypass the damaged road. In fact, as shown in Figure 4, if a rockfall event damages the road placed downhill (Provincial



road n. 6), drivers would have to drive along an alternative road, that is sensibly longer than the normal one, to reach Fresine and other nearby villages from the road SS42.

**Figure 4 -** Roads involved in the additional evaluation of the case study.

In order to estimate these additional costs, the following variables were considered:

- Difference in the lengths between the two roads (L):

calculated through GIS software.

| | |
|---|---|
| **Damaged road [km]** | 6.36 |
| **Alternative road [km]** | 12.66 |
| **Difference = Additional distance for drivers [km]** | 5.81 |

- Average cost per kilometre ($C_{km}$):

we considered a panel of 21 average cars (i.e., cars with average cost), equipped with different fuel supply systems. The number of different systems was chosen proportionally to the current figures of fuel supply systems derived from the Ministry of Infrastructures and Transport's statistics for Lombardy. For each car model considered, we gathered data on the average costs per kilometre from the National tables of kilometric costs for cars and motorcycles made available every year by the Automobile Club d'Italia (ACI). The average cost resulted in 0.459 €/km.

- Number of cars (N):

this data was already available, as it was obtained in the first part of the analysis. It resulted in 1,000 passages/day.

- Duration of worksite (W):

after the last rockfall event in Cevo (December 2017) it took two months to repair and re-open the damaged road. Due to the lack of more specific and detailed information/references, and assuming two months is very likely a non-ordinary road-interruption period, we adopted a precautionary approach and considered three different road-interruption periods associated to different severities of damages: two weeks, one month and two months.

The additional avoided damage was then calculated according to the following equation:

$$D = L * C_{km} * N * W$$

where:

*D = Additional avoided damage*

*L = Additional distance calculated as the difference between the ordinary road (Provincial road n. 6) and the alternative one.*

*$C_{km}$ = Average car (direct and indirect) costs per kilometre*

*N = Number of cars per day*

*W = Duration of the worksite, i.e. of the road-interruption period (number of days).*

Based on computations for the three different period considered, the following results were obtained:

| **Duration of the worksite [days]** | **Avoided damages [€]** | **Avoided damages per ha [€/ha]** |
|---|---|---|
| Two weeks (14 days) | 37,335.06 | 10,428.79 |
| One month (30 days) | 80,003.70 | 22,347.40 |
| Two months (60 days) | 160,007.40 | 44,694.80 |

Though this data strongly depends on the duration of the worksite (daily cost: 2,666.79 € that is about 745 €/ha per day of worksite and road-interruption), the results show that this component can potentially contribute to the global value of the forest: increasing the value per ha by 23 % to 97 % (based on the assumed road-interruption periods).

**Case study name:** *Valdidentro, Italy*
**Responsible partner:** *ERSAF (ETIFOR) - Simulations by UniMIB*

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 16 -** Localization of Valdidentro.

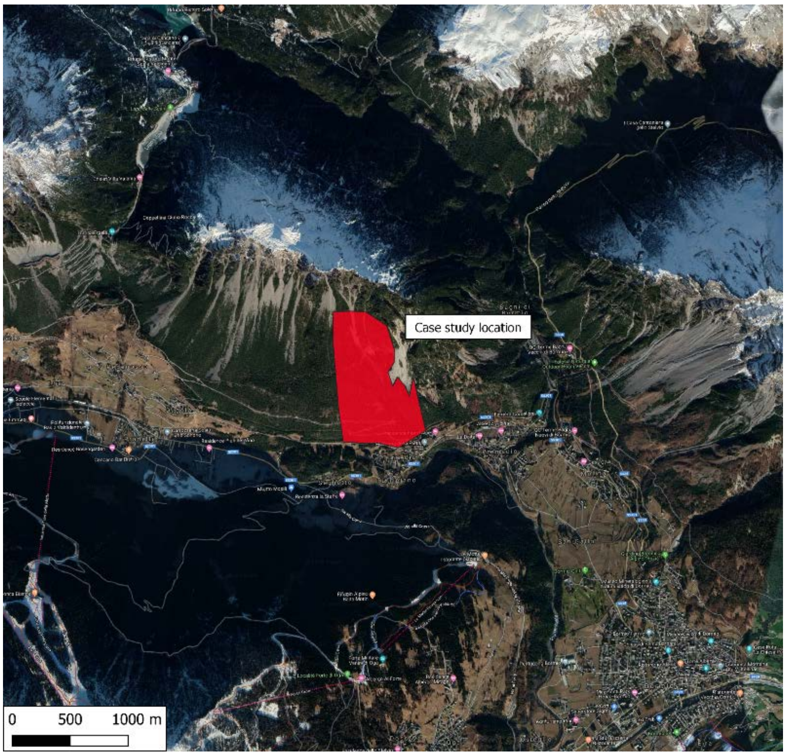



**Figure 17 -** Localization of the case study.

## 2. CASE STUDY DESCRIPTION

Valdidentro case study is located within the Province of Sondrio, Lombardy Region, between 1,360 and 2,400 m a.s.l..

It is a public owned forest area and its management plan is now out of date. Anyway, the plan didn't foresee any intervention because, due to the steep slope, the area is recognized as protection forest and therefore left to natural evolution.

The first simulation (SCENARIO A) underlined that, considering the 95° percentile, the forest has no protection function because of the predicted rock dimension (2,36 mc).

Therefore, another scenario was developed by reducing the block dimensions and it resulted that when the rock size equals 1 mc the forest is efficient in protecting one of the roads downhill (SCENARIO B).

The report will address the two above-mentioned scenarios separately.

## 3. CASE STUDY FEATURES

Figure 3 shows the elements characterizing the case study: the protection forest (bordered with a yellow line) has been identified starting from the source area (highlighted in orange) and by considering and buffering the most probable rocks' paths. This also enlightened the assets to be protected i.e. as the two roads located below the forest (highlighted in green and blue, respectively).

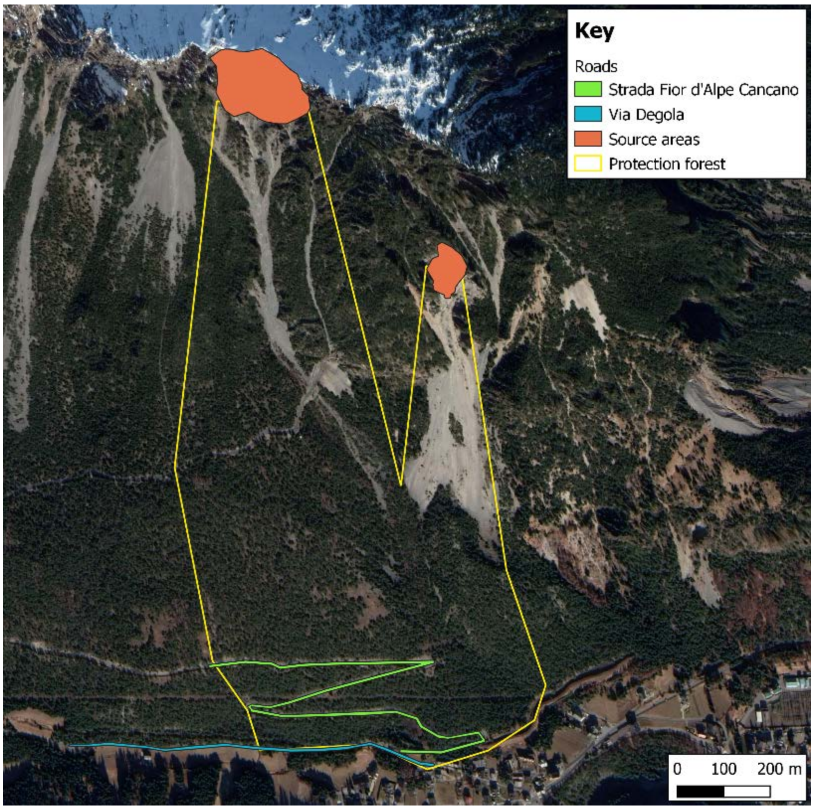



**Figure 3** - Source area, protection forest and the asset to be protected (road).

4. **ECONOMIC EVALUATION**

- Selected economic approach:

we choose the **ADM** in order to implement an alternative/different approach to the RCM. In addition to this, in our opinion the ADM could be easily communicated to/understood by citizens and policy makers.

- Selected time period for the evaluation*:*

**25 years**, in order to be consistent with the other case studies addressed within the project.

- Exposed assets:

exposed assets consist of the two roads standing below the forest, that are **road Fior d'Alpe Cancano** (total length of the risk-exposed tract: 1,390 m) and **via Degola** (total length of the risk-exposed tract: 540 m).

- Protection forests:

although information about the forest status is not updated, it can be described as a **low-density pine forest** (*Pinus sylvestris* L. and *Pinus mugo* Turra), with presence of some screes. The total area covered by the protection forest is **64.88 ha**.

- Forest effectiveness against rockfall (SCENARIO A):

| **Assets** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Road Fior d'Alpe Cancano | 3.47 | 2.59 | - 0.337 |
| Via Degola | 0.65 | 0.57 | - 0.135 |

the 95° percentile has been calculated from the dimensions of the boulders from previous events, showing a dimension of 2,36 mc. The efficiency simulations have been performed by Milano-Bicocca University team through the proprietary software HY-STONE. Based on simulation outcomes the forest apparently has a negative impact on the energy of the block, accelerating it. This is probably due to the size of the block that restricts the efficiency of the forest at the point that the behaviour of the latter does not perform well in the modelling software.

- Forest effectiveness against rockfall (SCENARIO B):

| **Asset** | **Kinetic energy WITH forest (1 mc) [kJ]** | **Kinetic energy WITHOUT forests (1 mc) [kJ]** | **ORPI** |
|---|---|---|---|
| Via Degola | 0.324 | 0.367 | 0.12 |

the table represents the results of the simulation with a 1 mc volume boulder. The only asset where an effect is shown is B.

- Value of the exposed assets (SCENARIO A):

| **Assets** | **Unitary value immovable [€/m]** | **Exposed area immovable [mq]** | **Unitary value movable [€]** | **Presence probability movable [/h]** | **Presence probability people [/h]** |
|---|---|---|---|---|---|
| A | 318.15 | 12 | 20,039 | 4 | 8 |
| B | 318.15 | 12 | 20,039 | 4 | 8 |

- Unitary value immovable:

obtained from Lombardy Region, Regional pricelist of public works - ed. 2019 (i.e., the official pricelist for public works in Lombardy Region), by considering the expected damage a rock with the selected size/volume could cause on an asphalt road.

- Exposed area immovable:

the area that could be affected by the damage and therefore could need to be repaired.

- Unitary value movable:

obtained from Fleet&Mobility, Mercato Auto Valore - ed. 2017 (i.e., Car Market Value), where the average purchase value of a car in Italy is estimated to be **20,039 €**.

- Presence probability movable**:**

obtained as an expert-based estimation by interviewing a transport/logistic engineer (Ministero delle Infrastrutture e dei Trasporti, 2018), who compared the road being assessed with average data for mountain roads at the national scale.

- Presence probability people:

we estimated an average of **two people** (i.e. 1 driver and 1 passenger) per car.

- Value of the exposed assets (SCENARIO B):

| **Asset** | **Unitary value immovable [€/m]** | **Exposed area immovable [mq]** | **Unitary value movable [€]** | **Presence probability movable [/h]** | **Presence probability people [/h]** |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| B | 148.25 | 12 | 20,039 | 4 | 8 |

### *5.* FOREST MANAGEMENT

The area is not managed and there are not planned forest operations that could affect forest value.

### *6.* RESULTS (SCENARIO A)

| | |
|---|---|
| **Overall avoided damage [€]** | 0 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to: **0 €**.

### *7.* RESULTS (SCENARIO B)

| | |
|---|---|
| **Overall avoided damage [€]** | 28,034 |
| **Overall discounted stumpage value [€]** | 0 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***28,034 €***
- *Unitary Protection Value* ***432 €/ha***
- *Yearly Protection Value* ***13 €/ha/y***

### *8.* CRITICAL ANALYSIS OF RESULTS

Some assumptions were necessary to perform the evaluation exercise:

- every rockfall event has the same dimension distribution;
- the expected rockfall causes the same damage as of similar past events;
- that the number of car passages per day on the road equals the average value estimated for similar roads at the national level.

As already reported, this case study didn't perform well in the first simulated scenario, nonetheless model outputs could be useful to inform further research activities regarding the protection function of irregular and sparse forests.

| Case study name: | *Cogolo, Italy* |
| --- | --- |
| **Responsible partner:** | *PAT - SFF* |

*1.* **GEOGRAPHICAL FRAMEWORK**


**Figure 1 -** Localization of Cogolo.


**Figure 2 -** Localization of the case study.

## 2. CASE STUDY DESCRIPTION

Forest on a deep hillslope in a small valley called “Val dela Mare”, near Cogolo village. The forest is composed from *Pinus cembra* L. and *Larix decidua* Miller where the latter represent 30 % of the forest plants. In the bottom of the forested slope, there is a tourist and leisure area that is used several times during the summertime. In addition to this area, a road passes throw the forest and it is used for Malga Mare restaurant and by workers of a hydroelectric power plant. In the upper part of the forest area and the road, there are several cliffs where rockfall events are generated. Due to the morphology of the slope, the distribution of the rockfall phenomena is different in the area with a heterogeneous spread of rock stack zones and forest stands.

## 3. CASE STUDY FEATURES

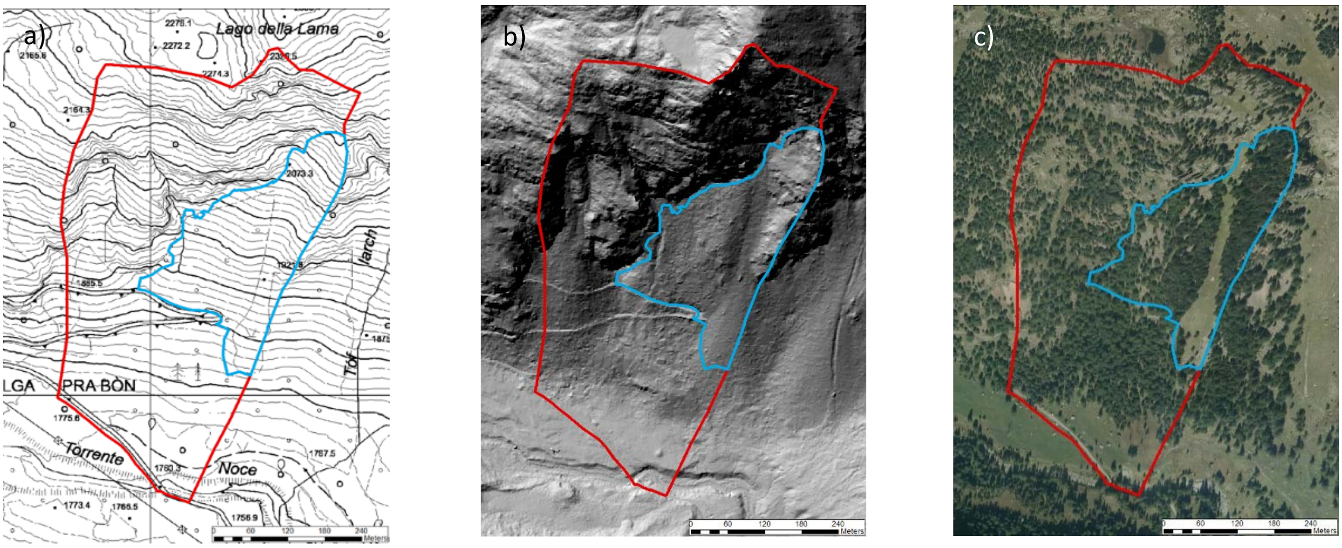



**Figure 3** - Case study (red polygon) and protection forest (blue polygon) in different forms: Regional Technical Paper (a); DEM (b); ortophoto (c).

## 4. ECONOMIC EVALUATION

- Selected economic approach:

the **ADM***,* it has been chosen this approach because it is possible consider indirect perspectives linked with forest functions, for example tourist and leisure functions of the forest (connected with human passages on the road). Addiction to the forest functions, the approach considers also the lack of economic income for the restaurant and the increase of costs for the hydroelectric power plant from a blocked road by a rockfall event.

- Selected time period for the evaluation*:*

**25 years**, according to the life expectancy of the protective structure.

- Exposed assets:

it's a part of the **road** that passes throw the protected forest. The asset is large about 3 m for a length of 140 m of asphalt road. No guardrail is present in the part of the asset.

- Protection forests:

the surface of the area is **5.20 ha** and the forest is an **uneven-aged stand**, with an average DBH of 33 cm. The average density is around 500 trees/ha and the composition is 70 % *Pinus cembra* L. and 30 % *Larix decidua* Miller;

- Forest effectiveness against rockfall:

| **Asset** | **Kinetic energy WITH forest (95° perc.) [kJ]** | **Kinetic energy WITHOUT forests (95° perc.) [kJ]** | **ORPI** |
|---|---|---|---|
| Road | 1,986 | 2,048 | 0.40 |

- Value of the exposed assets:

the data was taken from interview with local forest station and from technical office of the municipality of the area.

| **Asset** | **Unitary value immovable [€/]** | **Exposed area immovable [m]** | **Unitary value movable [€]** | **Presence probability movable [/h]** | **Presence probability people [/h]** |
|---|---|---|---|---|---|
| Road | 750 | 140 | 20,039 | 1.4 | 4.8 |

## *5.* FOREST MANAGEMENT

All forests of Cogolo municipality are management by a **Forest Management Plant**; in the forest of the case study it is not planned any kind of forest management due to steepness of the slope, the distance from the road and the low quality of the trees.

## *6.* RESULTS

| **Overall avoided damage [€]** | 46,787 |
|---|---|
| **Overall discounted stumpage value [€]** | 11 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***46,799 €***
- *Unitary Protection Value* ***9,000 €/ha***
- *Yearly Protection Value* ***281 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

Meetings with local stakeholders and experts will be held in autumn. At a first stage of testing the tool, we can just put in evidence several aspects of the working mechanism of the tool:

- it would be useful to include also indirect damages (helicopter costs for transporting the workers of the hydroelectric power and lack of income for 2 mountain restaurants on the top), globally at least 30.000 €/month in summer;
- it would be useful a guide with the concepts and formulas used to define the outputs, so that the user can verify if an input figure is accurate enough or not.

| Case study name: | *Seewände, Germany* |
| --- | --- |
| **Responsible partner:** | *BLW* |

## *1.* GEOGRAPHICAL FRAMEWORK


**Figure 1 -** Localization of Seewände.

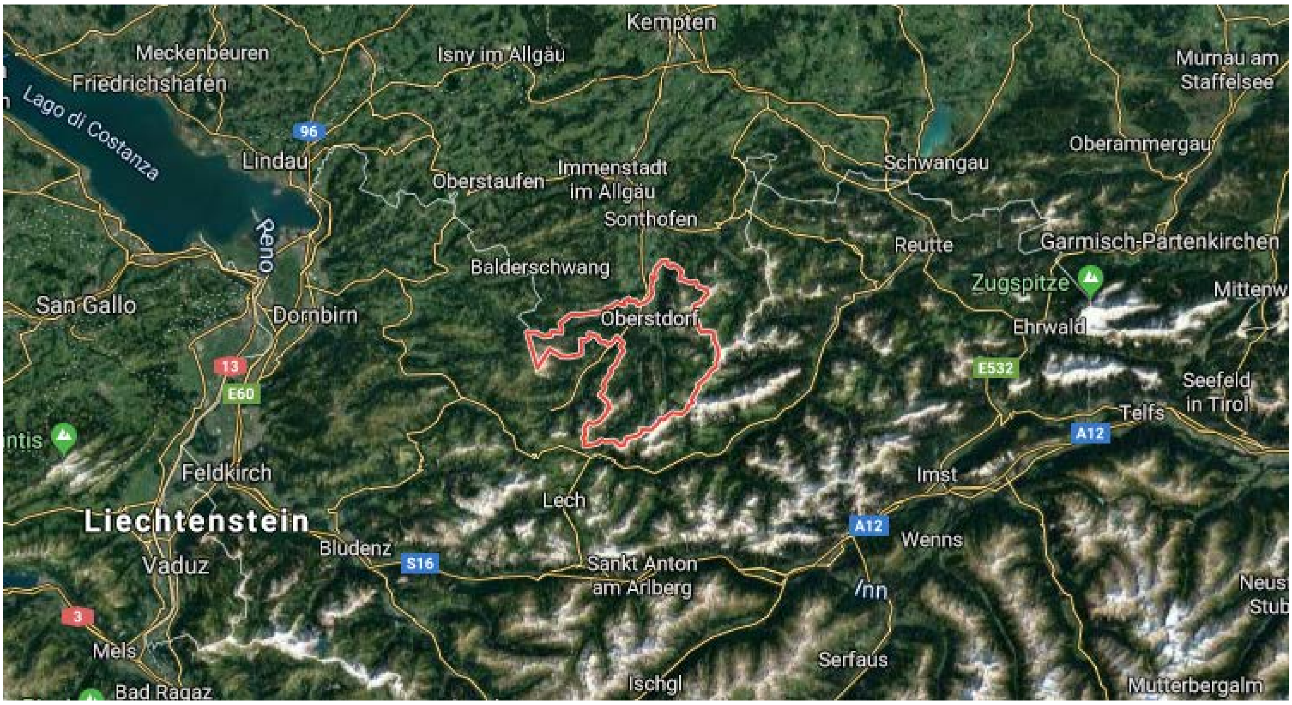



**Figure 18 -** Municipal boundaries of Oberstdorf.

## *2.* CASE STUDY DESCRIPTION

*N/A*

## 3. CASE STUDY FEATURES

Figure 3 delimits the boundaries of the protection forest in the regional technical map (3a), the ortophoto (3b) and the DTM (Digital Terrain Model - 3c).

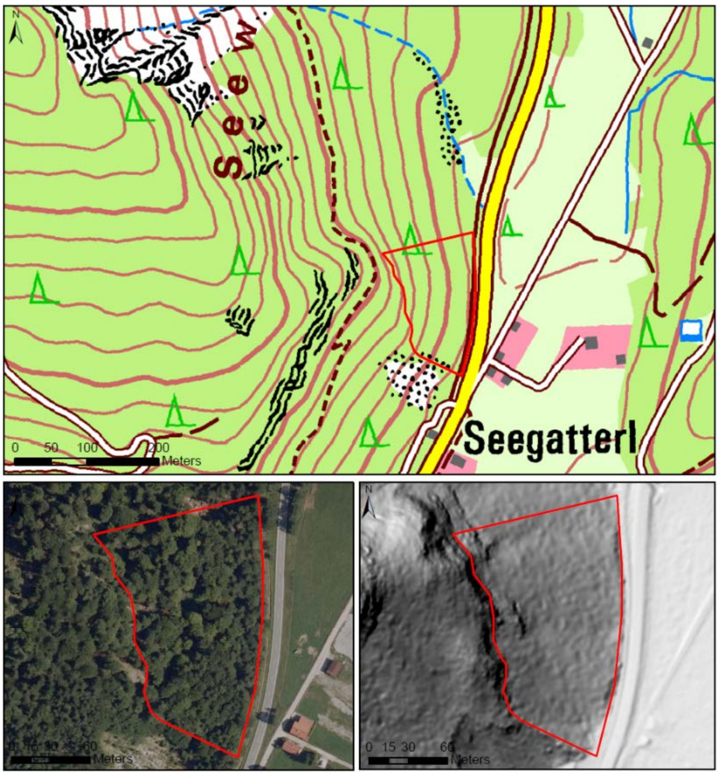



**Figure 3 –** Case study.

## 4. ECONOMIC EVALUATION

- Selected economic approach:

the **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the asset at risk, that is a road, is considered as the relevant damage potential.

- Selected time period for the evaluation*:*

**25 years**. This value is the result of several discussions with the partners of the project.

- Exposed assets:

the only asset is a 202 m stretch of **road**, which is frequented all year round.

- Protection forests:

N/A

- Forest effectiveness against rockfall:

| Asset | Kinetic energy WITH forest (95° perc.) [kJ] | Kinetic energy WITHOUT forests (95° perc.) [kJ] | ORPI |
|---|---|---|---|
| Road | 59 | 87 | 0.90 |

- Value of the exposed assets:

missing road value data. Of the movable property and the value of human life defined according to the ERSAF/ETIFOR project partners, presence of average annual daily traffic card machine (Bau und Verkehr, 2019).

| Asset | Unitary value immovable [€/m] | Exposed area Immovable [m] | Unitary value movable [€] | Presence probability movable [/h] | Presence probability people [/h] |
|---|---|---|---|---|---|
| Road | - | - | 20,039 | 84 | 168 |

## 5. FOREST MANAGEMENT

Total forest management costs are **€ 30,659**, broken down into the following items in Figure 4.

| Estimated costs for protection forest management at site Seegatterl Seewände | | |
|---|---|---|
| area [ha] | 1,7 | |
| | | |
| **A) initial investment to enhance protection function** | **calculation** | **total costs [€]** |
| cutting and debarking trees, storing them perpendicular to the slope | *20 stems each 1,5 m3 = 30 m3; labour costs 50 €/m* | 1500 |
| planting trees | *1000 plants, each 3,50 €* | 3500 |
| costst because cut down trees cannot be selled. german: "Nutzungsverzicht | *30 m3 at 75 €/m3* | 2250 |
| road closure during forest management activities | *1 day adiitional cost due to extra way for evry participant of average daily traffic: 16,3 km longer way * 0,30 €/km travelcosts * 2023 vehicles per day = 9892 €/day* | 9892 |
| | Sum | **17142** |
| | | |
| costs per hectar [€/ha] **10084** | | |
| | | |
| **B) following investments to maintain good level of protection** | **calculation** | **Kosten gesamt [€]** |
| *total costs every 10 years [€/ha]* | *half of costs for forest management + 1 day road closure* | ***13517*** |
| | | |
| costs per hectar [€/ha] **7951** | | |

**Figure 4 –** Forest management expenses.

## 6. RESULTS

| **Overall avoided damage [€]** | 69,833 |
|---|---|
| **Overall discounted stumpage value [€]** | 30,659 |

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* ***100,492 €***
- *Unitary Protection Value* ***60,211 €/ha***
- *Yearly Protection Value* ***1,880 €/ha/y***

## *7.* CRITICAL ANALYSIS OF RESULTS

The results obtained are in line with those in the literature (see Discussion and Conclusions).

# 4. Discussion and Conclusions

The values obtained by ASFORESEE have been compared with values present in the literature, for an indirect validation. The reference data were taken from case studies located in the same evaluation area, the Alpine arc, with the exception of French sites, located in the Auvergne-Rhône-Alpes region.

The risks considered in the case studies do not only refer to rockfall, there are avalanches, surface landslides and hydrogeological risk. The fact of considering different risks is due to the reduced presence in the literature of studies dealing with the evaluation of the protection service offered by the forest against rockfall (Bianchi et al. 2018).

What emerges, in literature, is that the protective value of the forest according to the RCM, presents a range from 137 to 700 €/ha/year (Table 1). While applying the ADM, there is a range from 1,400 to 5,000 €/ha/year (Table 2). The results obtained from the application of ASFORESEE are quite in line with those in the literature. This could be seen especially with the case studies that had a greater completeness of data. At the same time, it was noted that the main cause of deviation is due to the lack of some input data.

**Table 1 –** Case study in literature for the RCM.

| Case study | Considered risk | Value | U.M. |
|---|---|---|---|
| Trento, Italy (Notaro and Paletto 2004) | Gravitative* | 186.90 | €/ha/y |
| Trento, Italy (Goio, Gios, and Pollini 2008) | Hydrogeological | 212.19 | €/ha/y |
| Valdastico, Italy (Notaro and Paletto 2012) | Gravitative* | 284.20 | €/ha/y |
| Leiblachtal, Austria (Paletto et al. 2015) | Gravitative* | 707 | €/ha/y |
| ÖBF Land, Austria (Getzner et al. 2017) | Gravitative* | 268 | €/ha/y |

**Notes** *: rockfall, avalanches, mudflows and shallow landslides.

**Table 2 –** Case study in literature for the ADM.

| Case study | Risk considered | Value | U.M. |
|---|---|---|---|
| Le Freney, France (Cemagref, 2007) | Rockfall | 125,000 | €/ha |
| Andermatt, Swiss (Goio, Gios, and Pollini, 2008; Teich and Bebi, 2009) | Avalanches | 5,000 | €/ha/y |
| Veyrier-du-Lac, France (Cahen, 2010) | Rockfall | 1,400 | €/ha/y |
| Mendrisio, Swiss (Moos, 2018) | Rockfall | 3,818.67 | €/ha/y |

With regard to the ASFORESEE model emerge some strengths, such as the replicability, the use of few input data for the operation, the possibility to be used by technicians and decision makers and the fact of being an innovative tool. In the literature there was not yet a model to deal with such evaluations. At the same time, some limitations emerged. They lie in the choice of the spatial scale and the approximation between defensive work and forest.

With reference to the spatial scale, there is a limit for the application of ASFORESEE to scales larger than that of forest stands, such as landscape. Specifically, the limits for the ADM are intrinsic, since the assessment is "site-specific", while for the RCM, the application to larger spatial scales could negatively influence the quality of the result.

A possible solution is the adoption of socio-ecological systems, which consider the demand, the level of protection required by stakeholders and the supply, the protective service offered by the forest, at a wider spatial scale (Accastello, Blanc, and Brun 2019).

The second aspect concerns the approximation between defensive work and the forest. The first can be sized according to security requirements and the actual risk present, while the second can only be managed to improve its stability, often with short-term disadvantages (Motta and Haudemand 2000). Furthermore, in defensive work, the protective effectiveness is only guaranteed by its technical durability, in the face of increasingly high maintenance costs (Faber and Stewart 2003). In the case of the forest, on the other hand, the dynamics are different and since biotic and abiotic disturbance factors and the effect of ongoing climate change also occur, the protective effectiveness is subject to fluctuations over time and will never be higher than that offered by a defensive work (Dupire, 2011).

Moreover, ASFORESEE has an inherent limit. The results obtained by the two approaches are not comparable, since the methodology and the type of input data required are different. In the RCM the protective value is strictly forest dependent, while in the ADM the value is obviously influenced by the elements at risk.

In conclusion, a potential application of the ASFORESEE system could be within more complex methodologies such as multi-criteria decision support analyses or in cost-benefit analyses for strategic environmental assessments of risk mitigation plans and programmes, since it is able to provide scenarios.

## 5. Acknowledgements

This report was conducted within the Interreg Alpine Space programme (http://www.it.alpine-space.eu/). The authors deeply wish to thank the partners of Project n. 462 "RockTheAlps" who have contributed researching, and possibly providing, the studies that have been used within this work.

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