ASFORESEE: an AS harmonized methodology for protection FORest Ecosystem Services Economic Evaluation

WP4 - Deliverable D.T4.3.1

INTERREG Alpine Space Project 462: RockTheAlps

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Acronyms adopted in the Text:

ES: Ecosystem Service

Eco-DRR: Ecosystem-based solution for Disaster Risk Reduction

AS: Alpine Space

RC: Replacement Cost

AD: Avoided Damages

ORPI: Overall Rockfall Protection Index

ASFORESEE: Alpine Space FORest Ecosystem Services Economic Evaluation

Introduction

The Alpine Region is one of the most densely populated mountainous areas of the world, being inhabited by about 14M people unevenly distributed within its boundaries, (ALP. CONV., 2015). Here, in a perspective of a growing anthropic pressure and increasing magnitude and frequency of natural hazards triggered by climate change (Howard and Sterner, 2017; UNISDR, 2015), there is an increasing need for protection from these risks in order to protect the elements, as people, goods, infrastructures and productive activities, located in areas subjected to natural disasters (EEA, 2010).

Historically, this protection has been achieved in mountainous areas through two main strategies: building defensive facilities, as nets and barriers; or managing the mountain forests to maintain or improve the protection service they provide (Motta and Haudemand, 2000). The latter consists in the mitigation of hazards triggered by gravity, as rockfall, avalanches and shallow landslides due to the combined effect of soil stabilization and impediment created by the trunks (MA, 2003). In modern times, the approach based on artificial structure has clearly become predominant, but its adoption implies some disadvantages, as high maintenance costs, visual impact and alteration of natural environments (Holub and Huebl, 2008; Rimböck, et al., 2018). On the other hand, the ability of Ecosystem-based solutions for Disaster Risk Reduction (Eco-DRR) to provide affordable, low-impact and multifunctional solutions to risk mitigation is historically known and increasingly adopted (Dupire et al., 2016; Miura et al., 2015; Teich and Bebi, 2009; Moos et al., 2018). Hence, in order to favour the inclusion of such protective forests in the local risk management strategies, a reliable assessment of their function is essential (Grilli et al., 2015; Zoderer et al., 2016). Such assessment can be performed in several alternative ways: among those, monetary evaluations stand for their ability to translate environmental functions into economic terms, favouring their understanding from policy and decision makers (R. David Simpson, 1998).

In the previous deliverables of the Rock the Alps project, the past experiences available within the Alpine Space dealing with the economic evaluation of the rockfall protection service were investigated (Deliverable T.4.1.1 “State of the Art of Forest Protection Service Economic Assessment”). More than 20 studies resulted from the literature review, which highlighted a large variability both of the available methods and the forms of expression of the results, which were alternatively presented as values, i.e. a lump sum of money, or incomes, often expressed as money ha-1 year-1 (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. In order to define the methodological basis behind these studies, in the deliverable 4T.4.2.1 (“Economic Concepts for Evaluation of Risk Mitigation Strategies”) we described in depth the features of the different evaluation approaches 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).

Therefore, the aim of the deliverable T.43.1 “ASFORESEE : an AS Harmonized Methodology for Protection FORest Ecosystem Services Economic Evaluation” of the Alpine Space INTERREG project “Rock the Alps” is to provide a handbook presenting the ASFORESEE (Alpine Space FORest Ecosystem Services Economic Evaluation) model. Particularly, its methodology, general principles, concepts, workflow, the economic, forest and technical input data required, the output data and their uses for displaying the economic role of protection forest in rockfall risk mitigation strategies will be described. The model will perform an economic evaluation of the forest protection service, harmonising data from forest stands with technical and economic parameters into a replicable and standardized framework able to consider the societal needs for liveability and safety. The natural hazard considered is only rockfall, a typology of landslide confined to the removal of individual rocks (Dorren et al., 2005), which, despite its high specificity, constitutes a relevant issue for mountainous areas (Dorren, 2003). This economic model includes the two most common evaluation methods: the Replacement Cost (RC) approach and the Avoided Damages (AD) approach, to be adopted alternatively in relation to the features of the study area. In addition, the model is intended to be employed by decision makers and practitioners of Eco-DRR in any mountain region affected by rockfall, therefore its structure should aim at standardizing the assessment process and supplying easily understandable monetary information.

The ASFORESEE Model

The Framework of the Model

In consideration of the need to take simultaneously in account two alternative evaluation methods within the same model, the ASFORESEE structure has been developed in order to work in parallel for both. Nonetheless, some common aspects between the two are still present, as explained in the following sections (figure 1).

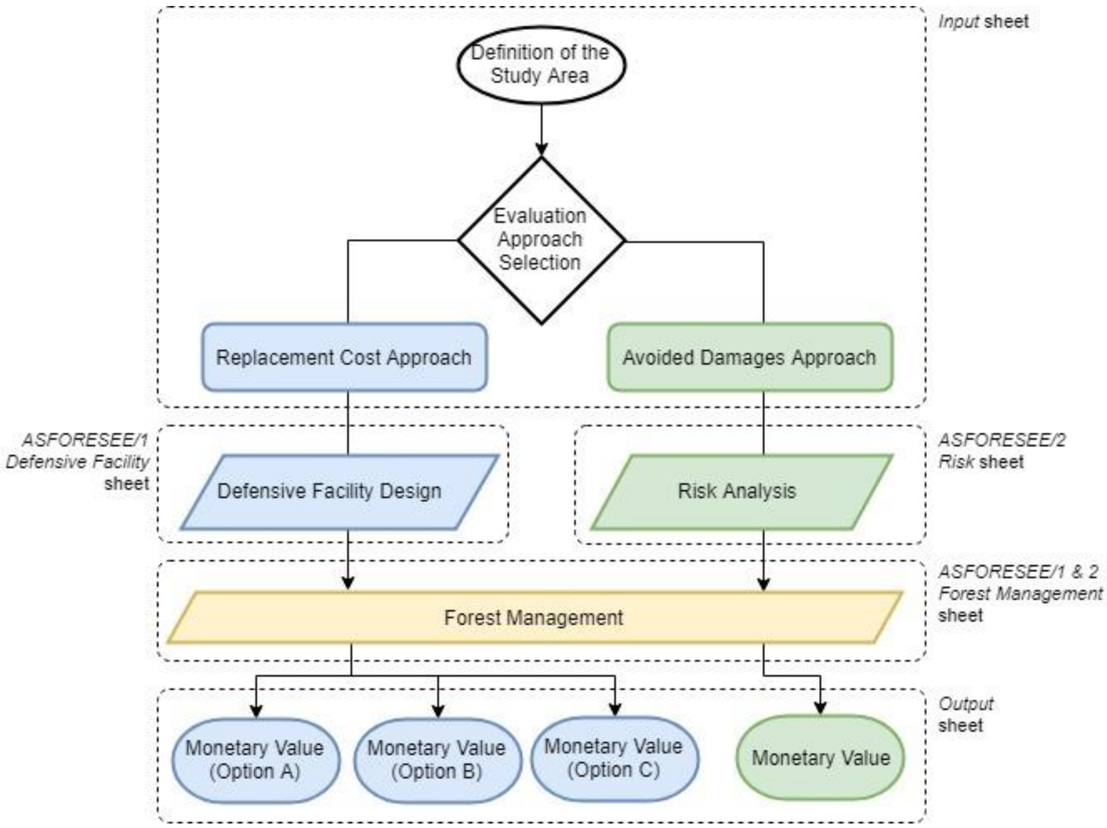


Figure 1: the framework of ASFORESEE with reference to the Excel sheets that constitute the model; in blue the components dealing with the RC approach only, in green those dealing with the AD only, in yellow their common components.

The flow chart represented in figure 1 depicts the conceptual framework underlying ASFORESEE. Once selected the study area, characterized by the presence of rockfall hazard, a forest and one or more exposed assets, the evaluation approach has to be selected. From this dichotomy, the model work in parallel, focusing on the specific methodological aspects that characterize the two methods. Finally, their result is represented by a monetary sum expressing the value of the protection ES that the forest provides against the rockfall risk.

Model Description and User Guide

The ASFORESEE model has been built in a Microsoft Excel environment, linking several sheets within the same file. This structure allowed to combine all the different data sources and create a friendly environment for the user.

The file is organized in 6 sheets, as shown in figure 2.

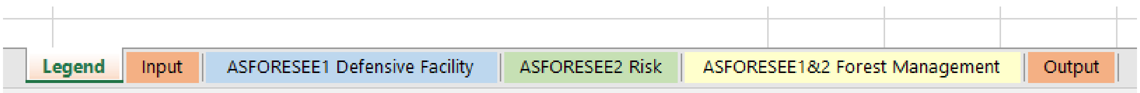


Figure 2: the division in sheets of ASFORESEE within the Excel file.

Where sheet “Legend” contains the information to interpret the content of the cells in relation to their format style;

“Input” contains all cells to be filled by the user to run the model;

“ASFORESEE 1 Defensive Facility” includes the calculations to design the needed of hypothetical defensive facility, and to estimate its cost;

“ASFORESEE 2 Risk” contains the calculations to estimate the risks of the different assets in the area exposed to rockfall;

“ASFORESEEE 1 & 2 Forest Management” computes the Stumpage Value of the forest interventions planned in the stand to maintain or increase its protective function;

“Output” delivers the result of the evaluation according to the selected approach.

In the following sections of the Handbook, each sheet is described in its components, accompanied with images of the file itself. Any value included in the images should be considered as a mere example, not related to any real case study.

Legend

The first sheet of the file contains the list of the different cell formats adopted throughout the sheets which compose ASFORESEE. For each of them the content that characterize the cell is described in order to provide the user a support in understanding the functioning of the model itself (Figure 3).

	A	B	C
1	**Legend**		
2	*20*	Cells To Be Filled by the User	
3	*1*	Switches To Be Turned On/Off by the User (With 0 or 1)	
4	3	Cells with Constant Data	
5	30	Cells with formulas	
6		Cells Exclusively Concerning the Replacement Cost Approach	
7		Cells Exclusively Concerning the Avoided Damages Approach	
8		Cells Pertaining to Both Approaches	
9		**In Bold the Main Results of Each Page and the Headers of Each Section**	

Figure 3: the "Legend" sheet of the Excel file.

Here the user is not supposed to take any action, but rather to use this list as a guide to understand the following sheets.

Input

In the second sheet of the model the user can find an extensive list of Input needed to run the model. This sheet is generally organized in four main columns (A, B, C and D) respectively showing the type of data needed, its value, its unit of measure and its range of possible values. These data are divided into four main areas, contoured with a thick black line, respectively named "Evaluation

Approach"; "Common Data"; "ASFORESEE/1 – Replacement Cost Approach" and "ASFORESEE/2 – Avoided Damages Approach".

Study Area

The first line is dedicated to name the study area name and select the evaluation approach to adopt (Figure 4).

	A	B
1	**Case Study:**	***Lorem Ipsum, Italy***
2		
3	**Evaluation Approach**	
4	**ASFORESEE/1 - Replacement Cost**	*1*
5	**ASFORESEE/2 - Avoided Damages**	*0*

Figure 4: the "Evaluation Approach" set of data in the Input sheet.

Evaluation Approach

The cells in red consist in a switch to be turned on or off by inserting the value "1" or "0" respectively. The definition of the data source determines which cells the user will have to fill in the following lines to make the model work. The two available approaches are the RC (named ASFORESEE/1 in the file) and the AD (named ASFORESEE/2). The inclusion of these two alternative methods is based on the findings of the previous deliverable T.4.1.1 and T.4.2.1. There, the available approaches were discussed in the light of their application to evaluate a regulation ES, and they resulted to be the most suitable ones for the aims of ASFORESEE.

Replacement Cost approach

ASFORESEE/1 is based on the RC approach, one of the most suitable methods to assess regulation and protective ES (Haines-Young and Potschin, 2012) and whose adoption in mountainous areas is well documented (Getzner et al., 2017; Grilli et al., 2015; Paletto et al., 2015). The approach states that the value of the protective function ensured by forests against rockfall is equal to the expenditures incurred to reproduce the same service with artificial means. Its application is subjected to three requisites: i) the artificial structure hypothesized to replace the forest must have the same effectiveness; ii) it must be the least costly available on the market, notwithstanding the first requisite; iii) there must be an interest of the people benefiting the service, to maintain and replace it, when missing (Bockstael et al., 2000). The intrinsic limitations of this approach are related mainly to the spatial scale of the evaluation. When dealing with landscape- or regional-scale evaluations, the uncertainties due to the assumptions needed to adopt the method are high (Bianchi et al., 2018). Moreover, this approach is not able to emphasize the importance of the different elements at risk, since sets its focus on the forest instead of on the objects of the protection.

The RC approach requires several technical, economic and modelling input to be combined. These data are listed in the following cells of the “Input” sheet of the file. The interactions of these information are resumed in the following flow chart, which represent the conceptual framework laying behind the monetary evaluation according to the RC approach (Figure 5).

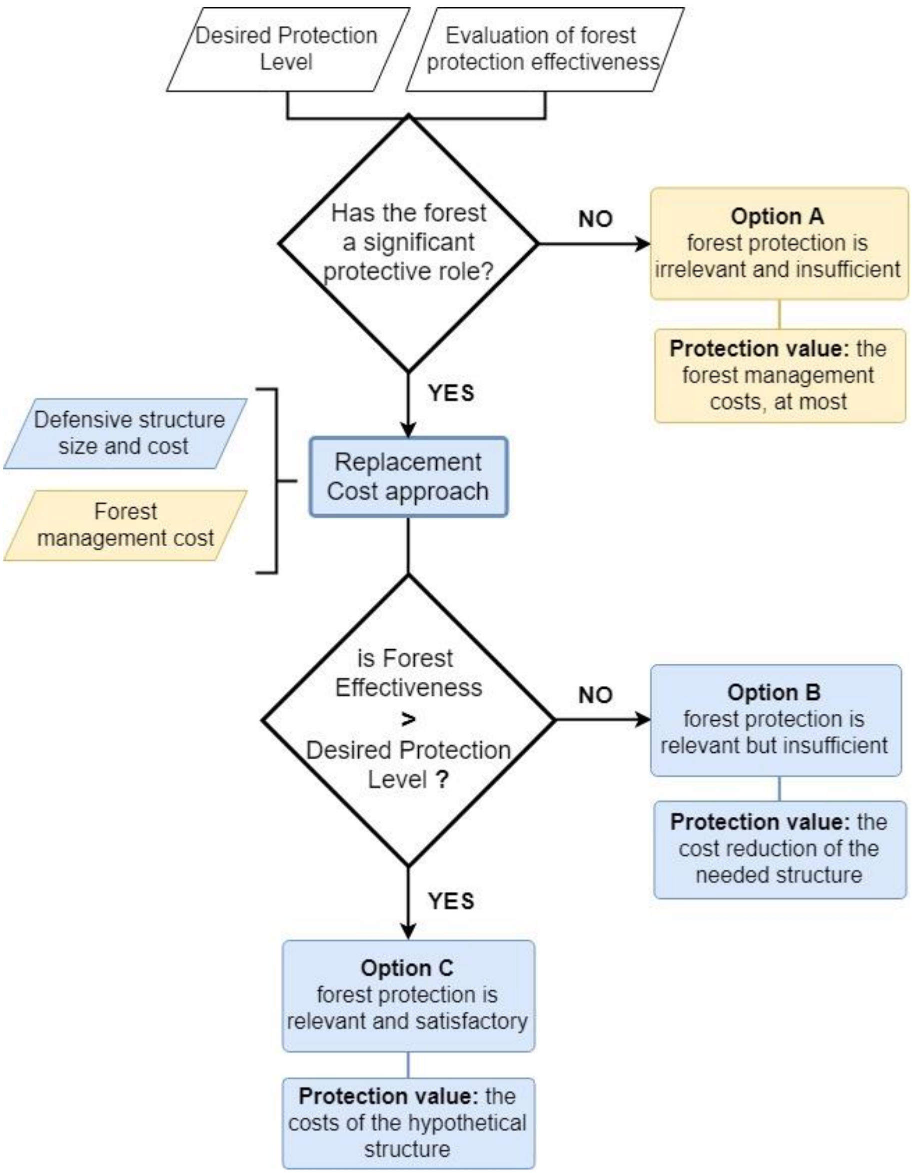


Figure 5: conceptual framework of ASFORESEE/1; in blue the components dealing with the RC approach only, in yellow the components in common with the AD approach.

The present framework defines three possible options to evaluate the protective service, in consideration of different factors involved. First, the role of the forest is verified in relation to its effectiveness against rockfall events and the need for protection of the stakeholders. Then, if its role is evaluated as relevant, the RC approach is adopted, assessing the expenditures related to forest management and defensive structures. Finally, a further discrimination is set to evaluate the forest performance in the light of a target protection level set by stakeholders.

Avoided Damages approach

ASFORESEE/2 instead, is based on the AD approach. This second evaluation method focuses on the object of this service, rather than on the subject providing the protection, as happened in the previous approach. Therefore, the value of the ES will be estimated in relation to the value of the assets protected by the forest (Cahen, 2010). In order to link together the rockfall hazard, the forest and the assets, the AD approach operated by a series of subordinate probabilities inter-related one to the other (Bianchi et al., 2018). Adopting such method implies also a greater consideration of the timespan of the evaluation. While for the Replacement Approach the time scale influence was limited to the discounting operation of the facility costs, here it determines the return period of the expected event, widely influencing the result of the evaluation. Since the rockfall hazard is recognized for its characteristics of scarce predictability (Žabota et al., 2019) in terms of intensity and frequency of the events, we assumed the expected event to be represented by the boulder having the 95th quantile diameter among those measured on field, with a return period of one event happening within the timespan considered for the evaluation. This decision represents the main assumption of ASFORESEE/2, but it is consistent with other experiences on the topic (Moos et al., 2018), with the data already available for ASFORESEE/1 and with the intrinsic features of this peculiar gravitational hazard. Once defined the probabilities of the rockfall event, the falling boulder is “followed” along its path, estimating its chances to cross the protection forest without being stopped and to hit and damage one of the assets at risk, being a real estate, a movable item or a person. Considering this set of combined probabilities, the values of the elements at risk and the expenses needed to manage the forest with a dedicated series of interventions aimed at maintain or improve its protective function, the value of this ES can be estimated. In consideration of the characteristics of this approach, ASFORESEE/2 is based on the following conceptual framework, which constitutes the methodological basis underlying its application (Figure 6).

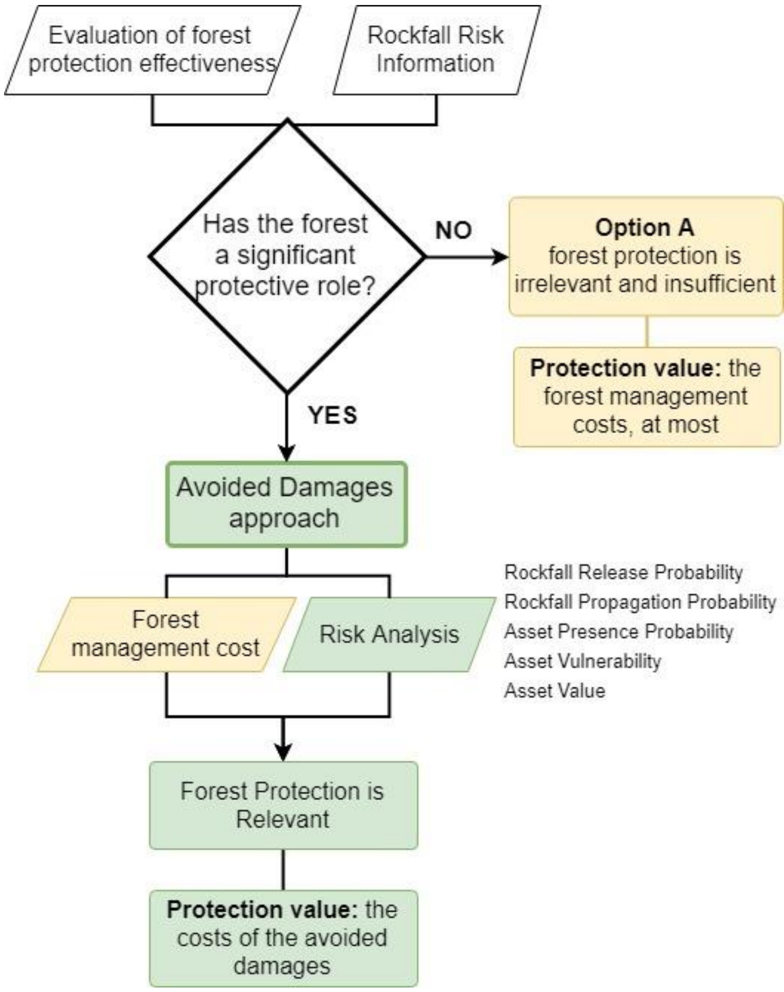


Figure 6: conceptual framework of ASFORESEE/2; in green the components dealing with the AD only, in yellow the components in common with the RC approach.

The framework presents two options to compute the forest protection service value. The first can be adopted for those cases where the stand is currently lacking of a relevant protective role, but this can be partially achieved within the timespan of the evaluation through a dedicated forest management. On the other hand, if the stand has a relevant protective role, the AD approach performs an analysis of the rockfall risk considering the different factors involved and matching its monetary results with the expenses of the forest management. Finally, the main results of ASFORESEE/2 is a monetary value estimating the rockfall protection service of the forest stand with this method. As ASFORESEE/1, this method is intended to be adopted at local level only, performing an evaluation of the service provided by one single forest stand.

It is worth to highlight that, since the two available approaches are strictly alternative, the user will follow a different path throughout the file in relation to the decision that was taken. Consequently, the economic results achieved with the two approaches cannot be compared, since based on a different conceptual basis. Based on the information presented previously, now the user should be able to select the most suitable approach in relation to the features of the study area and its aims. Particularly, if the case study is characterized by very high levels of protection demand from the stakeholders, due to specific assets to be protected for their value or importance (as schools, hospitals, artworks, monuments, …) the AD will be able to better reflect the peculiarities of such goods. On the other hand, when the user is dealing with a standard situation in which the implementation of artificial protection measures can be designed in a standardized way, the RC approach will better fit this feature.

Common Data

Once defined the evaluation approach, the user is asked to fill the cells of a second set of data containing the information in common among the two evaluation approaches. Therefore, the user will fill these cells despite of the selected approach. Here, the data pertain to different aspects of the case study and the evaluation (Figure 7).

7	**Common Data**	**Value**	**Unit of Measure**
8	**General**		
9	Timespan	*20*	*y*
10	Interest Rate	*0,02*	*%*
11	Area of the Protection Forest	*10,5*	*ha*
12	Kinetic Energy with Forest at Asset A	*12*	*kjoule*
13	Kinetic Energy without Forest at Asset A	*1570*	*kjoule*
14	Forest Effectiveness (ORPI) for Asset A	*0,49*	-
15	Forest Effectiveness (ORPI) for Asset B (optional)	*0,898*	-
16	Forest Effectiveness (ORPI) for Asset C (optional)	*1*	-
17	Width to Be Protected For Asset A	*150*	*m*
18	Width to Be Protected For Asset B (optional)	*50*	*m*
19	Width to Be Protected For Asset C (optional)	*10*	*m*

Figure 7: the “Common Data” set in the Input sheet/1.

Timespan

The first information needed for this set of data is the timespan considered for the evaluation. When defining this value, the user should consider the large influence it has on several other variables of the model and their precision. Precisely, the timespan will influence the number of forest intervention in the area, the times the defensive facilities will have to be replaced and the probability of a rockfall event involving a block having a 95th quantile diameter.

Interest Rate

Similarly, the interest rate will highly influence the economic results of the evaluation too. Therefore, it is important to underline how significant it is for the user to select the most proper rate. According to the review of Bianchi et al (2018), the most common interest rate for the economic evaluation of the rockfall protection service is the 2%.

Area of the Protection Forest

The third value is the area of the case study, that is the extension of the protection forest. It should be remarked how ASFORESEE is a strictly stand-level model, built to evaluate the service provided by a well-defined forest stand against a single, or a close group of rockfall sources and protecting some assets whose safety is valued by the stakeholders.

Kinetic Energy

Then, a list of technical data characterise the second part of this set of data. Specifically, information concerning the kinetic energy developed by the falling block having the 95th quantile of the diameter measured in the area has to be inserted, both considering the effectiveness of the forest in dissipating it and not considering it. This information can be deducted from the elaboration needed to compute the forest effectiveness index (see the following paragraph) and therefore is adopted by ASFORESEE as an input data and not as a value to be computed autonomously. This value can usually be referred to the specific location of some asset of interest (e.g. a road, a house, …) where to build the protection measures, here named Asset A.

Forest Effectiveness

Another relevant data is the forest effectiveness, that is the ability of the forest to mitigate rockfall events. This value has been defined for the model adopting an index able to measure the effect of the trees to reduce frequency and intensity of the phenomena. Therefore, we considered only the rockfall events where the forest can provide an effective protective functions, i.e. falling blocks with a volume lower than 10 m^3. In consideration of the aims of the work, ASFORESEE adopts the ORPI (Overall rockfall Protection Index) (Dupire et al., 2016). This index is based on a statistical approach and computes the maximum kinetics energy of a rock falling along the slope and modelling also how much of this energy can be dissipated by the forest. This function is expressed with a value between 0 and 1 in relation to the percentage of falling blocks stopped by the protection forest sited along their trajectory. In ASFORESEE, the ORPI is always referred the location where the assets of interest (A, B or C) are situated. Anyway, it is worth to underline how these values remains independent from the model and adopted as mere input data: therefore, here we will not include any guideline on how to collect and measure this value. Within the RockTheAlps project, the Working Group n.2 (Deliverable D.T2.5.1 “TORRID Toolbox”) made these information available, in order to allow the ASFORESEE model to work.

Width to be protected

Finally, the last information required is the width of the area to be protected, a useful data to design the rockfall net barriers with ASFORESEE/1 or to compute the value of the assets at risk with ASFORESEE/2.

Data Source

The second part of this set of Common Data starts with a second switch, where the user should define the data source of the Stumpage Value of the silvicultural interventions planned in the protection forest within the considered timespan by inserting “1” or “0” to turn it on or off (Figure 8).

21	**Data Source**	From Project	To Be Computed	
22	Forest management	*0*	*1*	
23				
24	**IF "From Project"**			
25	Overall Discounted Stumpage Value	*-10500*	*€*	
26	**OR**			
27	**IF "To Be Computed"**			
28	**Forest**			
29	Volume/ha	*293*	*m3/ha*	
30	Yearly Increment	*1,33*	*m3/ha/y*	
31	**Forest inverventions**			
32	**Intervention Typology**	***A***		
33	Block Exploitation Aptitude from SEM	*0,52*	*-*	
34	Year of Intervention	*0*	*y*	
35	Time between Two Interventions	*30*	*y*	
36	Area of Intervention	*5*	*ha*	
37	Harvest Intensity	*0,2*	*%*	
38	**Intervention Typology**	***B (optional)***		
39	Block Exploitation Aptitude from SEM	*0,48*	*-*	
40	Year of Intervention	*15*	*y*	
41	Time between Two Interventions	*30*	*y*	
42	Area of Intervention	*2,27*	*ha*	

Figure 8: the "Common Data" set in the Input sheet/2.

IF "From Project"

If selecting the "From project" option, then the user should directly insert the requested monetary value. This value can possibly obtained from intervention projects already performed or from the Forest Management Plan of the stand, if available. Its value should be composed by forest interventions costs, planning, administration, supervision and management costs, road and track maintenance costs.

IF "To Be Computed"

Otherwise, selecting "To be computed" this monetary value can be calculated by ASFORESEE. Anyway, the two options are strictly alternative: completing one of them prevent the user to complete the remaining one. Finally, it is important to remember that only the discounted monetary values of the expenditures should be inserted in the cells. As emerges from the figures 8 and 9 the selection of a data source implies a very different number of input data to be inserted in the model. This is consequence of the need to compute the stumpage value of the interventions within the model. To perform such evaluation, we adopted the SEM, an economic model developed by Accastello et al. (2017). SEM allows computing the stumpage value of a forest harvest comparing different working strategy and considering the environmental and logistic features of the stand and their influence of the productivity of the intervention.

Forest Stand Features

The first input to insert to run SEM deals with the features of the forest stand and of the intervention planned in it during the considered timespan in order to maintain or improve its protective function. ASFORESEE can consider up to two different intervention typologies that can be repeated one time each, according to the user's needs. For each of them some information are needed, mainly dealing with the timeline of these operations and their harvest intensity.

Working Strategy Information

In order to compute an economic balance of such interventions, several data concerning the working strategy adopted, the machinery and its costs, the manpower, the hourly yields of the operations and the revenues deriving from the various wood assortments are needed. Differently from the other information, the strategies available to perform the operations with are activated by a switch, which works as the previous ones with the values "0" or "1" (Figure 9). Since these information required a high level of knowledge in the field of silviculture and forest harvesting, disposing of a Forest Management Plan of the area or referring to experts' knowledge to define these values is highly recommended.

43	Harvest Intensity	0%	-
44	**Operation**	**Strategy**	
45	Felling and Processing	0	
46	Bunching	0	
47	Extraction with Forwarder	0	
48	Extraction with Skidder	0	
49	Extraction by Hauling	0	
50	Extraction with Cable Logging System	0	
51	**Manpower**	Share of work	Gross Wage (€/h)
52	Head of Logging Operations	0%	21
53	Common Worker	0%	19,41
54	**Assortments**	Share of volume	Market Price (€/mc)
55	Saw logs	0%	120
56	First Quality Poles	0%	80
57	Second Quality Poles	0%	60
58	Industrial logs	0%	50
59	Firewood	0%	30
60	Chips and pellet	0%	30
61	Tannin	0%	20
62	Other (to specify)	0%	20
63	Timber Losses	0%	-
64	**Machinery Costs**		
65	Tractor + Winch	0	€/h
66	Chainsaw	0	€/h
67	Skidder	0	€/h
68	Forwarder	0	€/h
69	Cable Logging System	0	€/h

Figure 9: the “Common Data” set in the Input sheet/3.

The third set of data in the Input sheet of the model concerns the RC approach only, therefore the user is not requested to fill these cells if the other approach was selected previously (Figure 10).

72	**ASFORESEE/1 - Replacement Cost Approach**			
73	**Protection Demand Side**			**Range**
74	Desired Protection Level from Stakeholders	75%	-	0 to 1
75	Survey link	https://www.survio.com/survey/d/A9Y2J4X2O8S2P3F6Y		
76	Score from Survey	22	-	5 to 25
77				
78	**Data Source**	From Project	To Be Computed	
79	Defensive Facility	0	1	
80				
81	**IF "From Project"**			
82	Discounted Cost of the Protective Structure	450000	€	
83	**OR**			
84	**IF "To Be Computed"**			
85	**Safety Factors**			**Range**
86	Human Risk Factor	1	-	1,00 to 1,20
87	Block Factor	1,02	-	1,02 to 1,10
88	Topographic factor	1,05	-	1,02 to 1,10
89	**Net Barrier Cost**			
90	for Max Kinetic Energy of 1000 KJ	231,81	€/m²	
91	for Max Kinetic Energy of 1500 KJ	262,7	€/m²	
92	for Max Kinetic Energy of 2000 KJ	303,9	€/m²	
93	for Max Kinetic Energy of 3000 KJ	427,53	€/m²	
94	for Max Kinetic Energy of > 4500 KJ	468,74	€/m²	

Figure 10: the "ASFORESEE/1 – Replacement Cost Approach" set of data in the Input sheet.

Protection Demand Side

ASFORESEE/1 adopts a "ES-inspired" approach to evaluate the protection service provided by forests, recognizing a "demand" side of this ES and a "supply" side provided by the protection forest stands. According to this approach, only if there is a need for this protection from rockfall by the society the ES provided by the forest occurs (Gret-Regamey et al., 2012). Therefore, in order to measure the value of this function, both demand and supply have to be assessed (Rheinberger and Treich, 2017). For the protection ES, a quali-quantitative evaluation of the demand can be implemented, considering both technical and social factors (Villamagna et al., 2013) in order to define a "desired protection level" from the stakeholders, which can vary in relation to the importance of the good at risk (Wolff et al., 2015). For example, in some contexts the protection supplied by the forest, could result sufficient to fulfil stakeholders expectations; while in others the need to resist any possible event, regardless of its intensity and frequency, justifies the implementation of artificial measures (Fidej et al., 2015). In ASFORESEE/1, the demand for protection is currently assessed in a quali-quantitative way involving the stakeholders affected by the rockfall risk. The actors to be involved are first selected among those having specific roles in the area concerning the management and planning of forest, infrastructures and public safety. First, risk classes have been defined, like those adopted in the PAI (Hydrogeological Master Plan), described below:

- 25% (low): expected marginal economic damage;
- 50% (average): Damage that does not affect the safety of people and which partially impair the functionality of economic activities;
- 75% (high): Possible effects on the safety of inhabitants, serious functional damage to buildings and infrastructure, and partial loss of activity functionality socio-economic;
- 100% (very high): possible loss of life, infrastructure and destruction of economic activities.

Then, a specific survey is set to collect their expectations for the protection of the goods at risks in relation to their value, perceived or economic (Figure 11, 12, 13 and 14). The survey is composed by five questions on the topic of demand for protection, plus few other questions for statistical purposes only.

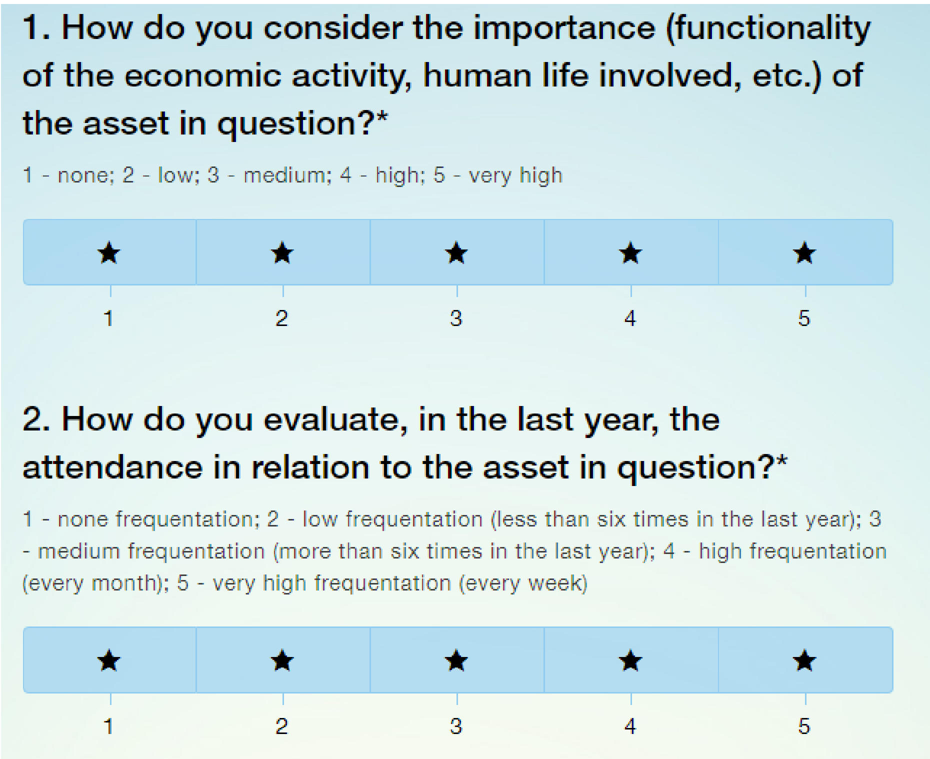
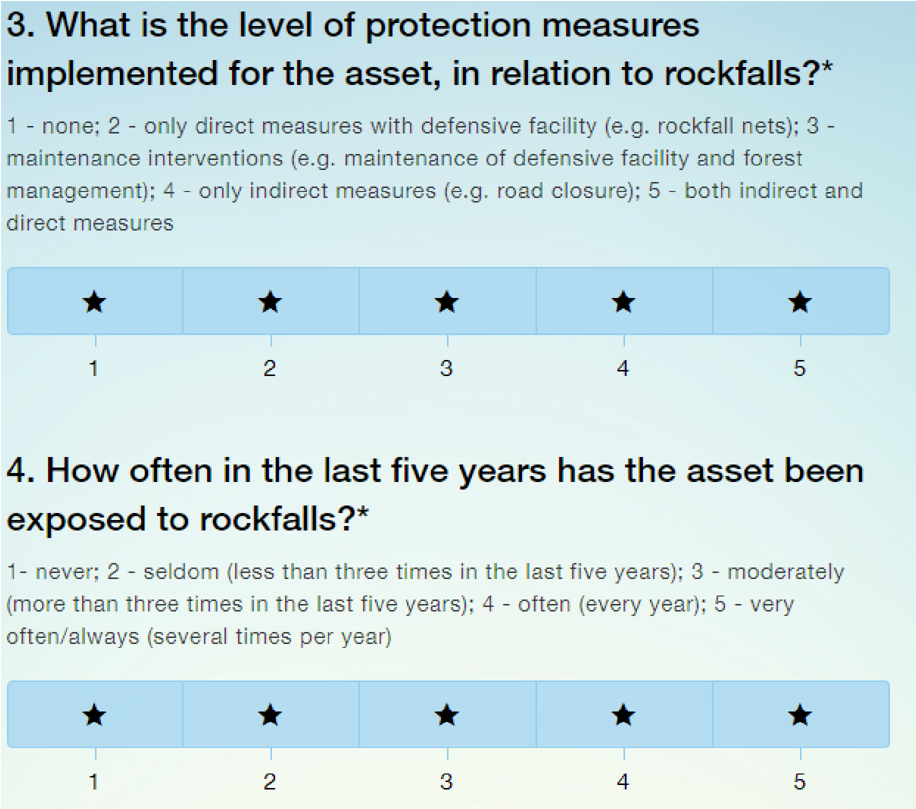


Figure 11: question 1 and 2 of the survey included in the Input sheet.



3. What is the level of protection measures implemented for the asset, in relation to rockfalls?*

1 - none; 2 - only direct measures with defensive facility (e.g. rockfall nets); 3 - maintenance interventions (e.g. maintenance of defensive facility and forest management); 4 - only indirect measures (e.g. road closure); 5 - both indirect and direct measures

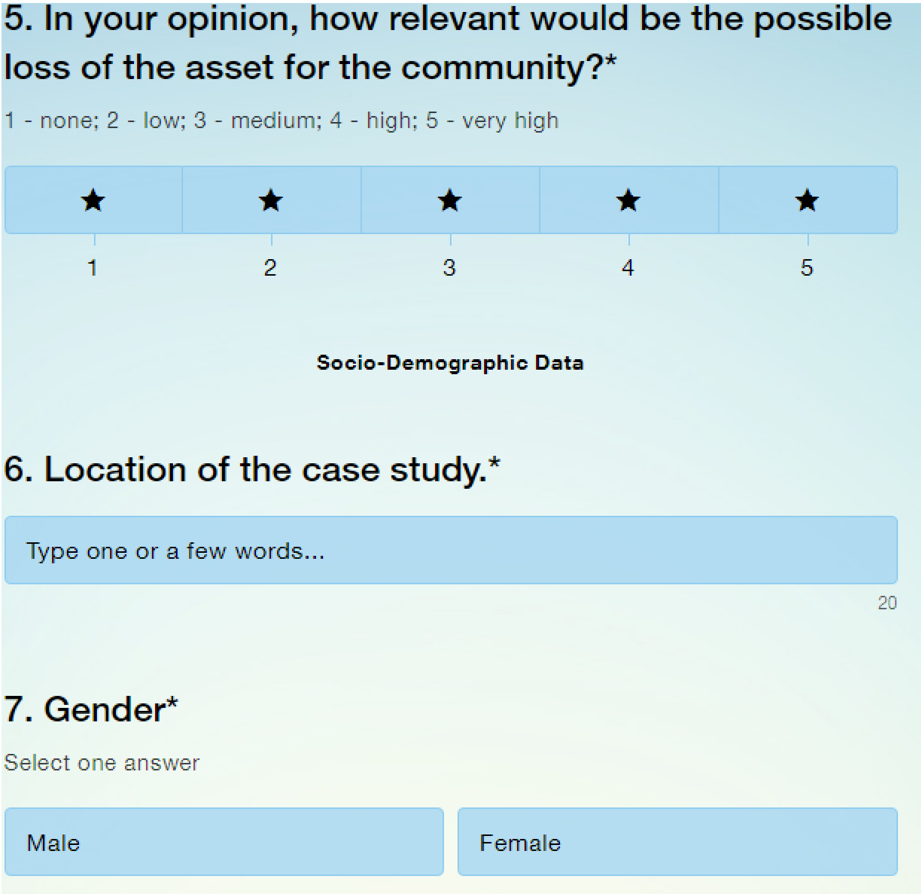
★	★	★	★	★
1	2	3	4	5

4. How often in the last five years has the asset been exposed to rockfalls?*

1- never; 2 - seldom (less than three times in the last five years); 3 - moderately (more than three times in the last five years); 4 - often (every year); 5 - very often/always (several times per year)

★	★	★	★	★
1	2	3	4	5

Figure 12: question 3 and 4 of the survey included in the Input sheet.



5. In your opinion, how relevant would be the possible loss of the asset for the community?*

1 - none; 2 - low; 3 - medium; 4 - high; 5 - very high

★	★	★	★	★
1	2	3	4	5

Socio-Demographic Data

6. Location of the case study.*

Type one or a few words...

20

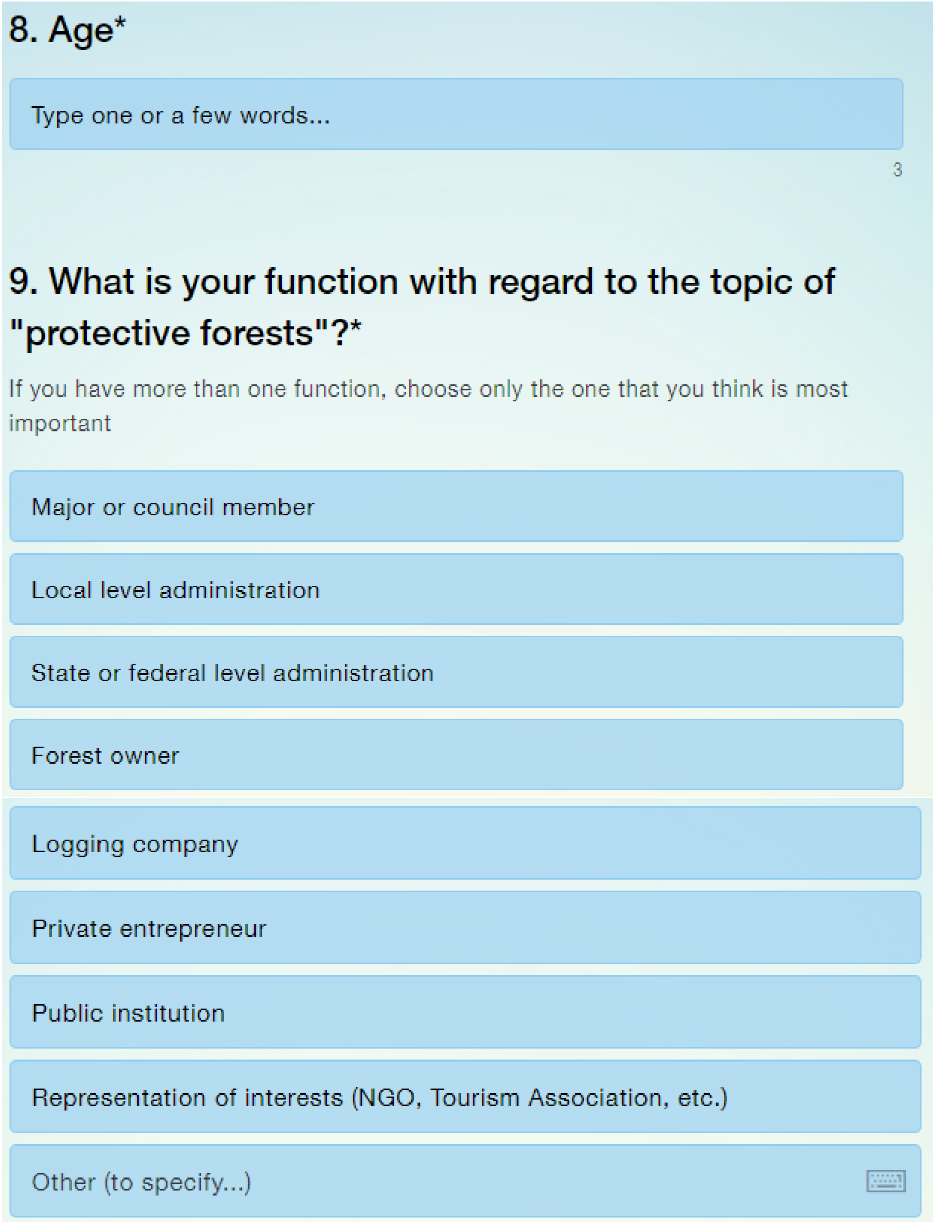
7. Gender*

Select one answer

Male

Female

Figure 13: question 5 and following of the survey included in the Input sheet.


8. Age*

Type one or a few words...

3

9. What is your function with regard to the topic of "protective forests"?*

If you have more than one function, choose only the one that you think is most important

Major or council member

Local level administration

State or federal level administration

Forest owner

Logging company

Private entrepreneur

Public institution

Representation of interests (NGO, Tourism Association, etc.)

Other (to specify...)

Figure 14: final questions of the survey included in the Input sheet.

Finally, the score obtained from the survey, obtained summing the scores from 1 to 5 assigned to each of the first five questions, will be integrated as a sort of *malus* or *bonus* at the risk class chosen (under 17 points will be a *malus*, while above it will be a *bonus*).

Discounted Cost of the Net Barriers

The following set of data requested is represented by the unitary cost of the net barriers to be designed for the case study (fig. 10). This information will constitute one of the major input of the RC approach in order to estimate the expenditures for the facility needed to integrate or substitute the forest. As explained earlier in this section, the sources of this monetary value can vary largely, therefore a switch was inserted to select it in relation to the information available. The user can fill the “from project” section only, if information from an actual project of net barriers implementation are available. Otherwise, he is asked to fill an extensive list of cells to design the rockfall net barriers, that is the standard facility adopted by ASFORESEE.

Safety Factors

In order to design the barriers in compliance with the ETAG 027 regulation (see the “ASFORESEE/1 Defensive Facility” section for its description), a list of safety factors is included in the requested data. These values are related to different aspects of the structure: particularly, the first is related to the level of risk for people and goods in the case study, and varies among 1.00 and 1.02. The second is a boulder-related factor considering the reliability of the data adopted to estimate the mass of the target block (values between 1.02 to 1.10 with decreasing data quality); and the last is a topographic factor considering the topographic information available on the area at risk (values from 1.02 to 1.10 with decreasing data quality).

Net Barrier Cost

Finally, the unitary costs are divided in relation to the maximum amount of kinetic energy the net can absorb, which has been inserted in the previous set. The user is free to fill only the cells of interest, leaving empty, or with null values, those below or above the needed energy level. The source of these costs, as well as the project possibly available, can vary from regional or national price lists, grey literature or previous projects in similar working conditions (Giacchetti and Grimod, 2014; Gottardi and Govoni, 2010; Piedmont Region, 2018).

The last box of the Input sheet is dedicated to the data needed for the AD approach only, selected by the user with the first switch of the model. Here, the data pertains mainly to the features of the assets located in the area at risk where the forest has a protective role in mitigating the rockfall events (Figure 15).

ASFORESEE/2 - Avoided Damages Approach		
Assets in Hazard Prone Areas		
Property A	Building	Road
	0	1
Immovable		
Unitary Value	5,76	€/m or €/mq or €/mc
Exposed Area	100,00	m or mq
Vulnerability	0,70	
Movable		
Unitary Value	0,00	€
Presence Probability	0,0	/h
Vulnerability	0,00	
People		
Human Life Value	4427000,00	€
Presence Probability	0,1	/h
Lethality	0,5	
Property B (Optional)	Building	Road
	0	1
Immovable		
Unitary Value	11,60	€/m or €/mq or €/mc
Exposed Area	0,00	m or mq
Vulnerability	0,40	
Movable		
Unitary Value	25000,00	€
Presence Probability	1,0	/h
Vulnerability	1,00	
People		
Human Life Value	4427000,00	€
Presence Probability	1,0	/h
Lethality	0,5	
Property C (Optional)	Building	Road
	0	1
Immovable		
Unitary Value	11,60	€/m or €/mq or €/mc
Exposed Area	0,00	m or mq
Vulnerability	0,20	
Movable		
Unitary Value	25000,00	€
Presence Probability	3,0	/h
Vulnerability	1,00	
People		
Human Life Value	4427000,00	€
Presence Probability	5,0	/h
Lethality	0,5	

Figure 15: the "ASFORESEE/2 – Avoided Damages Approach" set of data in the Input sheet.

Assets in Hazard Prone Areas

Particularly, the model can consider up to three different asset location (named A, B and C), including three kind of assets each, which can be considered or not in relation to the need of the users and the study area features. These goods are divided into immovable assets, as buildings and infrastructures; movable items, as cars and other moving objects; and people. For each of these categories the user is requested to insert their unitary economic value, the effective exposed area (only for immovable assets), the probability of their presence and their vulnerability to the rockfall event. The economic value of such assets can be derived from market or insurance values. Concerning the presence probability deserves some clarifications: the value for real estates was set to 1 since their presence is constant; for the other assets instead we decided to fix a parameter of presence per hour, which seems consistent with the timeframe of a rockfall event. Finally, the vulnerability expresses the percentage of structural damages in consequence of the expected rockfall event (a boulder having a 95th quantile diameter), while the lethality is the probability of being killed by the rock when hit. All probabilities are always expressed with values comprised between 0 and 1.

ASFORESEE/1 Defensive Facility

The third sheet of the file is dedicated to the first approach only. Here, the defensive facility needed to estimate the value of the protection service offered by the forest is designed in a standardized way and evaluated in its building, maintenance and removal cost. In this sheet and in the following ones the user is not supposed to insert any additional information nor make any modification of the content of the cells. They, instead, allow the user to understand the nuts-and-bolts of the model, investigating in detail its connections and the relation between the various data source. These sheets, moreover, share a similar structure that characterize all of these “technical” sheets of the file. First, a “RESULT” line is placed at the beginning of the sheet, showing the results of the several computations achieved in the sheet, then, a series of equations and connections among cells is shown in detail, allowing the user to follow the application of the method.

The "ASFORESEE 1 Defensive Facility" sheet is structured in two main parts which respectively concerns the estimation of the overall discounted building cost of a standard defensive which considers the role of the forest in mitigating the rockfall risk, and one which is not considering it. These two monetary values constitute the main result of the sheet and are reported in its first lines (Figure 16 and 17).

	A	B	C
1	**Defensive facility: Design and Costs**		
2			
3	RESULT:		
4	**Overall Discounted Building Cost WITHOUT Forest**	527333 **€**	

Figure 16: the main results of the "ASFORESEE 1 Defensive facility" sheet/1.

E	F	G
Overall Discounted Building Cost WITH Forest	130393 **€**	

Figure 17: the main results of the "ASFORESEE 1 Defensive facility" sheet/2.

The second part of the sheet ("COMPUTATION IN DETAILS") deploys all the necessary steps to design and size a proper defensive facility based on the specific characteristics of the case study (Figure 18). The procedure is the same in the right-hand side of the sheet, where, considering the forest, only the kinetic energy absorbed by the structure differs (Figure 19).

6	COMPUTATION IN DETAILS:		
7	**Design WITHOUT the forest**		
8	**ETAG 027 Kinetic Energy**	1681	**Kjoule**
9			
10	**Rockfall Net Energy Classes**		
11	Maximum Absorbable energy (kJ)	Heigth	Unit of Measure
12	1000	3	m
13	2000	3,5	m
14	5000	5	m
15	10000	6	m
16			
17	**Rockfall Net Characteristics**		
18	Kit Width	30	m
19	Expected Service Life	25	y
20	SEL Coefficient	3	
21	SEL Kinetic energy	5044	Kjoule
22	Kit Height	6	m
23	Kit cost	84373	€/m2
24			
25	**Building cost**		
26	Number of Kit Needed	5	
27	Overall Kit cost	421866	€
28	Ancillary Expenditures	25%	%
29	**Overall Facility Cost**	**527333**	**€**
30	Unitary Facility Cost	3516	€/m
31			
32	**Removing and Replacing Cost**		
33	Number of Facility Replacements	0	-
34	**Cost of Removing the Facility**	**105467**	**€**

Figure 18: the computations of the “ASFORESEE 1 Defensive facility” sheet/1.

Design WITH the forest		
ETAG 027 Kinetic Energy	**13**	**Kjoule**
Rockfall Net Energy Classes		
Maximum Absorbable energy (kJ)	Heigth	Unit of Measure
1000	3	m
2000	3,5	m
5000	5	m
10000	6	m
Rockfall Net Characteristics		
Kit Width	30	m
Expected Service Life	25	y
SEL Coefficient	3	
SEL Kinetic energy	39	Kjoule
Kit Height	3	m
Kit cost	20863	€/m2
Building cost		
Number of Kit Needed	5	
Overall Kit cost	104315	€
Ancillary Expenditures	25%	%
Overall Facility Cost	**130393**	**€**
Unitary Facility Cost	869	€/m
Removing and Replacing Cost		
Number of Facility Replacements	0	-
Cost of Removing the Facility	**26079**	**€**

Figure 19: the computations of the "ASFORESEE 1 Defensive facility" sheet/2.

Net Barriers Design

In order to harmonize the structural characteristics of the defensive facilities, needed or hypothetical, able to supply the desired protection service, ASFORESEE adopted the most common typology of structure available: the rockfall nets barriers. These barriers are a passive defensive structure constituted by an hexagonal mesh linked to metal poles fastened to the slope (Gottardi and Govoni, 2010). This structure was selected as standard for ASFORESEE because of its common employment in mountainous areas, its versatility, cost-effectiveness and easy installation (Rimböck, et al., 2018). Moreover, due to a specific European regulation defining building and testing methodologies, called ETAG027 (EOTA, 2012), it is possible to standardize its sizing, enabling the adoption of a common design. Therefore, these guidelines have been employed by ASFORESEE to size the artificial defensive facilities in relation to the features of the rockfall phenomena.

ETAG 027 Kinetic Energy

The main parameter needed for this operation is the target kinetic energy, that is the energy developed by a falling block having the 95th quantile diameter. Following a probabilistic approach, this value is defined in consequence of a field survey, where the fallen boulders are measured in their diameter (Dussauge et al., 2003). This parameter is consistent with the input data needed for the ORPI, in order to ease the field surveys, and it has been adopted to evaluate the expected events of the AD approach too.

SEL coefficient

This value is multiplied with an additional safety factor named Service Energy Level (SEL) assuming a constant value of 3, as defined by the ETAG027 regulation. This factor is compliant with the precautionary principle that characterize the whole model, particularly in relation to the intensity of the rockfall event and the defensive facilities sizing (Bourrier et al., 2015; MBIE et al., 2016).

Height of the Facility

The resulting energy value is used to set other parameters of the facility: its height and the resistance of the materials. Thus, the designed facility is compliant with the ETAG 027, able to bear multiple impacts suffering a minimal efficiency reduction, and does not require any extraordinary maintenance activity (Grimod and Giacchetti, 2014).

Width of the Facility

Once defined height and resistance of the facility, its sizing is completed with its width, derived from the input sheet. Within the present model, one line of net barrier has been considered sufficient to replace the effectiveness provided by the protection forest. This assumption is consistent with the range of events in which forests can play a relevant role and satisfies the requirements of least expenditure, given an equal level of effectiveness, established by the RC approach (Bockstael et al., 2000).

Building Cost of the Facility

Once designed the facility, the last step is the definition of its overall cost in order to obtain an overall sum that constitutes the basis of the RC approach (Dupire, 2011). This operation is achieved summing up the building cost of the structure, the expenditures for its removal at the end of it service life and the cost of implementing a new facility. The last two value, anyway, can be disregarded when the considered timespan is shorter or equal to the expected service life of the facility.

ASFORESEE/2 Risk

A similar structure characterizes the "ASFORESEE 2 Risk" sheet of the model, where the rockfall risks are evaluated in relation to the assets located in the exposed area. This sheet, concerning the AD approach only, presents a results box in the first lines, and then the computations are listed in detail in the following lines (Figure 20). The result achieved in this sheet is constituted by an economic evaluation of the damages to the assets at risk avoided due to the presence of the protection forest.

	A	B	C
1	**Risk Evaluation**		
2			
3	RESULT:		
4	**Overall Avoided Damage**	21167 **€**	

Figure 20: the results of the "ASFORESEE 2 Risk" sheet.

The second part of the sheet presents the series of equation needed to compute this value. Here we can find three main areas, one for each asset, where the probabilities of the event to happen, to reach the asset and to damage it are linked to its monetary value. The procedure adopted to compute the overall value of the damages avoided by the forest follows the works of Cahen (2010), building a series is subordinated probabilities that “describe” the rockfall event along its path from the cliff to the asset. Moreover, a “Time division” table is situated on the right side of the sheet in order to allow the different probabilities to operate on a common time scale (Figure 21 and 22).

COMPUTATION IN DETAILS:					
Asset A				**Time Division**	
Rockfall Event duration	1	min		1	Year
Probabilities	**Value**	**Unit of Measure**		365	Days per Year
Block Release Probability	0,0000000761	-		8760	Hours per Year
Block Propagation Probability	0,510	-		525600	Minutes per Year
Immovable Property Presence Probability	1			24	Hours per Day
Movable Property Presence Probability	0,0000000	-		60	Minutes per Hour
People Presence Probability	0,0000694				
Damages					
Total Value of the Immovable Property	576,00				
Potential Damage to Immovable Property	40320	€			
Potential Damage to Movable Property	0	€			
Potential Damage to People	154	€			
Discounted Damage to Immovable Property	24576	€			
Discounted Damage to Movable Property	0	€			
Discounted Damage to People	94	€			
Overall Damage	24670	€			
Overall Damage WITH Forest	0,000958	€			
Damage Avoided by the Forest	**24670**	**€**			

Figure 21: the computations of the “ASFORESEE 2 Risk” sheet/1.

Asset B (Optional)		
Rockfall Event duration	1	min
Probabilities	**Value**	**Unit of Measure**
Block Release Probability	0,0000000761	-
Block Propagation Probability	0,510	
Immovable Property Presence Probability	1	-
Movable Property Presence Probability	0,0000000	-
People Presence Probability	0,0000694	
Damages		
Total Value of the Immovable Property	0,00	
Potential Damage to Immovable Property	0	€
Potential Damage to Movable Property	25000	€
Potential Damage to People	0	€
Discounted Damage to Immovable Property	0	€
Discounted Damage to Movable Property	15238	€
Discounted Damage to People	0	€
Overall Damage	15238	€
Overall Damage WITH Forest	0,000000	€
Damage Avoided by the Forest	**15238**	€

Asset C (Optional)		
Rockfall Event duration	1	min
Probabilities	**Value**	**Unit of Measure**
Block Release Probability	0,0000000761	-
Block Propagation Probability	0,510	
Immovable Property Presence Probability	1	-
Movable Property Presence Probability	0,0000000	-
People Presence Probability	0,0000694	
Damages		
Total Value of the Immovable Property	0,00	
Potential Damage to Immovable Property	0	€
Potential Damage to Movable Property	25000	€
Potential Damage to People	0	€
Discounted Damage to Immovable Property	0	€
Discounted Damage to Movable Property	15238	€
Discounted Damage to People	0	€
Overall Damage	15238	€
Overall Damage WITH Forest	0,000000	€
Damage Avoided by the Forest	**15238**	€

Figure 22: the computations of the “ASFORESEE 2 Risk” sheet/2.

Block Release Probability

Specifically, we first estimate the block release probability as the chance of the block having a 95th quantile diameter to fall once during the timespan considered for the evaluation.

Block Propagation Probability

Then, the probability of its trajectory to cross the forests without being stopped results from the opposite value of the ORPI index.

Asset Features

Finally, the features of the assets at risk are involved in the estimation. First, their presence is evaluated; then, their total value (obtained from unitary value and effective exposed area – sheet “Input”), their potential damages are evaluated and discounted. Given the characteristics of the rockfall event, ASFORESEE set its duration equal to 1 minute in the time scale. The other probabilistic values of the model are referred to this time scale too.

ASFORESEE/1&2 Forest Management

The fifth sheet of the model is named “ASFORESEE/1&2 forest Management” and is the only sheet in common for both the evaluation approaches available. In this sheet too, the user is not asked to enter any additional information to those already inserted in the Input sheet. Here, the Stumpage Value, that is the economic balance of costs and revenues of the forest interventions to be performed in the stand, is computed. Similarly, to the previous ones, this sheet presents a result heading and then a list of computations needed to obtain this value (Figure 23). These equations are repeated for both the interventions typologies and their eventual repetition.

	A	B	C
1	**Forest Management Cost**		
2			
3	RESULT:		
4	**Forest Management Cost**		
5	Overall Discounted Stumpage Value Interve	-2632 €	
6	Overall Discounted Stumpage Value Interve	-2129 €	
7	**Overall Discounted Stumpage Value**	**-4760,45 €**	

Figure 23: the results of the "ASFORESEE1&2 forest Management" sheet.

The forest management is the last element contributing to the protection value in relation to the silvicultural activities carried out in the stand. Silviculture in rockfall protection forests mainly consists in diversifying the stand structure by intervening regularly, every 10 to 15 years (Rammer et al., 2015), to support the establishment of 40 cm or more diameter class and to develop a wealthy regeneration. This approach aims to maintain, and possibly increase, the level of protection ensured by the forest stand ensuring, in the meanwhile, its resilience, stability and perpetuation. On the other hand, often these interventions results in negative stumpage values due to the high harvesting costs and the low productivity rates, often situated in steep areas (Accastello et al., 2018; Notaro and Paletto, 2012). ASFORESEE estimates the management expenditures with data that are usually included in the Forest Management Plan of the stand. Therefore, their use does not require any further data collection phase. The net present value of the forest management expenses has been computed summing up the discounted stumpage values of all the planned interventions (Figure 24, 25, 26 and 27).

COMPUTATION IN DETAILS:			
Intervention Features			
Intervention Typology	A		
Intervention Number	1		
Current Volume in the Harvest Area	0,00	m3	
Harvested Volume	0,0	m3	
Final Volume	0	m3	
Extracted Wood Volume	0	mc	
Operation	**Minimum Yield (mc/h/worker)**	**Maximum Yield (mc/h/worker)**	**Yield difference**
Felling and Processing	1,15	3,13	1,98
Bunching	0,92	6,55	5,63
Extraction with Forwarder	6,00	16,33	10,33
Extraction with Skidder	3,20	7,90	4,70
Extraction by Hauling	2,35	6,35	4,00
Extraction with Cable Logging System	3,00	26,67	23,67
Operation Yields			
Felling and Processing	0,00	mc/h/worker	
Bunching	0,00	mc/h/worker	
Extraction with Forwarder	0,00	mc/h/worker	
Extraction with Skidder	0,00	mc/h/worker	
Extraction by Hauling	0,00	mc/h/worker	
Extraction with Cable Logging System	0,00	mc/h/worker	
Manpower			
Weighted Mean Cost	0,00	€/h	
REVENUES			
Wood Assortment	**Volume**		
Saw logs	0,00	mc	
First Quality Poles	0,00	mc	
Second Quality Poles	0,00	mc	
Industrial logs	0,00	mc	
Firewood	0,00	mc	
Chips and pellet	0,00	mc	
Tannin	0,00	mc	
Other (to specify)	0,00	mc	
Wood Assortment	**Revenues**		
Saw logs	0,00	€	
First Quality Poles	0,00	€	
Second Quality Poles	0,00	€	

Figure 24: the computations of forest intervention A in the “ASFORESEE1&2 forest Management” sheet/1.

Industrial logs	0,00	€	
Firewood	0,00	€	
Chips and pellet	0,00	€	
Tannin	0,00	€	
Other (to specify)	0,00	€	
Total	0,00	€	
COSTS			
Harvest Site Preparation			
Hours of Preparation	0	h	
Harvest Site Preparation Cost	0,00	€	
Felling and Processing			
Duration	0,0	h	
Chainsaw Daily Usage	6	h/die	
Chansaw Overall cost	0	€	
Mapower Cost	0,00	€	
Overall Felling and Processing Cost	0,00	€	
Unitary Cost	0,00	€/mc	
Bunching			
Duration	0,0	h	
Machinery Overall cost	0	€	
Mapower Cost	0,00	€	
Overall Bunching Cost	0,00	€	
Unitary Cost	0,00	€/mc	
Extraction			
Duration	0,00	h	
Machinery Overall cost	0	€	
Mapower Cost	0,00	€	
Overall Extraction Cost	0,00	€	
Unitary Cost	0,00	€/mc	
RESUME			
Overall Machinery Cost	0	€	
Overall Manpower Cost	0	€	
Harvest Cost	0	€	
Share of General Costs	10%	-	
Overall General Costs	0	€	
Overall Intervention Cost	0	€	
Unitary Cost	0,00	€	
Stumpage Value	**0**	**€**	
Stumpage Price	**0,00**	**€/mc**	
Intervention Duration	0,0	h	
Intervention Weighted Mean Yield	0,00	mc/die	

Figure 25: the computations of the forest intervention A in the "ASFORESEE1&2 forest Management" sheet/2.

Intervention Features			
Intervention Typology	A		
Intervention number	2		
Is this Intervention within the Timespan?	YES		
Current Volume	0,00	m3	
Harvested volume	0,0	m3	
Finale volume	0	m3	
Extracted Wood volume	0	mc	
Operation	**Minimum Yield (mc/h/worker)**	**Maximum Yield (mc/h/worker)**	**Yield difference**
Felling and Processing	1,15	3,13	1,98
Bunching	0,92	6,55	5,63
Extraction with Forwarder	6,00	16,33	10,33
Extraction with Skidder	3,20	7,90	4,70
Extraction by Hauling	2,35	6,35	4,00
Extraction with Cable Logging System	3,00	26,67	23,67
Operation Yields			
Felling and Processing	0,00	mc/h/worker	
Bunching	0,00	mc/h/worker	
Extraction with Forwarder	0,00	mc/h/worker	
Extraction with Skidder	0,00	mc/h/worker	
Extraction by Hauling	0,00	mc/h/worker	
Extraction with Cable Logging System	0,00	mc/h/worker	
Manpower			
Weighted Mean Cost	0,00	€/h	
REVENUES			
Wood Assortment	**Volume**		
Saw logs	0,00	mc	
First Quality Poles	0,00	mc	
Second Quality Poles	0,00	mc	
Industrial logs	0,00	mc	
Firewood	0,00	mc	
Chips and pellet	0,00	mc	
Tannin	0,00	mc	
Other (to specify)	0,00	mc	
Wood Assortment	**Revenues**		
Saw logs	0,00	€	
First Quality Poles	0,00	€	
Second Quality Poles	0,00	€	

Figure 26: the computations of the forest intervention B in the “ASFORESEE1&2 forest Management” sheet/3.

Industrial logs	0,00	€	
Firewood	0,00	€	
Chips and pellet	0,00	€	
Tannin	0,00	€	
Other (to specify)	0,00	€	
Total	0,00	€	
COSTS			
Harvest Site Preparation			
Hours of Preparation	0	h	
Harvest Site Preparation Cost	0,00	€	
Felling and Processing			
Duration	#DIV/0!	h	
Chainsaw Daily Usage	6	h/die	
Chansaw Overall cost	#DIV/0!	€	
Mapower Cost	#DIV/0!	€	
Overall Felling and Processing Cost	#DIV/0!	€	
Unitary Cost	0,00	€/mc	
Bunching			
Duration	#DIV/0!	h	
Machinery Overall cost	#DIV/0!	€	
Mapower Cost	#DIV/0!	€	
Overall Bunching Cost	#DIV/0!	€	
Unitary Cost	0,00	€/mc	
Extraction			
Duration	#DIV/0!	h	
Machinery Overall cost	#DIV/0!	€	
Mapower Cost	#DIV/0!	€	
Overall Extraction Cost	#DIV/0!	€	
Unitary Cost	0,00	€/mc	
RESUME			
Overall Machinery Cost	#DIV/0!	€	
Overall Manpower Cost	#DIV/0!	€	
Harvest Cost	#DIV/0!	€	
Share of General Costs	10%	-	
Overall General Costs	#DIV/0!	€	
Overall Intervention Cost	#DIV/0!	€	
Unitary Cost	0,00	€/mc	
Stumpage Value	**#DIV/0!**	**€**	
Stumpage Price	**0,00**	**€/mc**	
Intervention Duration	#DIV/0!	h	
Intervention Weighted Mean Yield	#DIV/0!	mc/die	

Figure 27: the computations of the forest intervention B in the "ASFORESEE1&2 forest Management" sheet/4.

Output

Finally, in the last sheet of the model, its outputs are presented, providing a different economic value of the protection ES in relation to the selected approach. In the first lines, in fact, a reminder of the decision took by the user in the Input sheet is inserted in order to address the user toward the correct section of the sheet. Below this, we find five areas where the results are presented: four concerning the RC approach, and one for the AD approach (figure 28).

	A	B	C
1	**Case Study:**	***Lorem Ipsum, Italy***	
2			
3	You selected the approach:	Replacement Cost--> See Line 5	
4			
5	**ASFORESEE/1 - Replacement Cost Approach**		
6	Has the Forest a Relevant Protection Role?	YES	
7	Is the Stakeholders Need for Protection Fulfilled?	NO	
8	**The Forest Protection Value is Option:**	**2 --> See Line 15**	
9			
10	**Option A: the Forest Protection is Irrelevant and Insufficient**		
11	Monetary Protection Value	4760	€
12	Unitary Protection Value	453	€/ha
13	Yearly Protection Value	19	€/ha/y
14			
15	**Option A: the Forest Protection is Relevant But Insufficient**		
16	Monetary Protection Value	401700	€
17	Unitary Protection Value	38257	€/ha
18	Yearly Protection Value	1575	€/ha/y
19			
20	**Option A: the Forest Protection is Relevant and Sufficient**		
21	Monetary Protection Value	263153	€
22	Unitary Protection Value	25062	€/ha
23	Yearly Protection Value	1031	€/ha/y
24			
25	**ASFORESEE/2 - Avoided Damages Approach**		
26	Monetary Protection Value	16406	€
27	Unitary Protection Value	1563	€/ha
28	Yearly Protection Value	64	€/ha/y

Figure 28: the results of model presented in the “Output” sheet.

Replacement Cost approach

Particularly, the four sections dealing with the RC approach deploy the monetary evaluation into three alternative options. These options take in account all possible conditions the forest effectiveness and the stakeholders’ needs can establish. First, in this first box it is first verified if the forest has a relevant protective role for the case study. Then, the evaluation of the demand for protection of the stakeholders is compared with the values of the forest effectiveness. The answer to these two questions will determine the most suitable option to assess the value of the protection service, indicated to the user in the bottom line of the first box in blue.

Evaluation Options

The description of these options is reported below:

Option A. The forest is not able to reduce the rockfall risk in a relevant way;

Option B. The forest significantly mitigates, but not eliminates, the rockfall risk;

Option C. The forest is completely effective in mitigating the rockfall risk and can be considered sufficient and reliable.

The definition of these alternative options represent the keystone of ASFORESEE, allowing to define the most suitable approach to evaluate the protection ES of the forest. Each of these options involve a different equation developed to provide a protective value able to reflect the actual role of the stand in risk mitigation. In details, the evaluation is performed for each option as follows:

Option A. Here the protective role of the forest is marginal, therefore its protective value is null, because of the inability of the forest to mitigate the risk and/or the lack of interest in the protection service by the stakeholders. At most, the protective value of the forest can be estimated as the silvicultural expenditures incurred to support this improvement, but only when a chance for the stand to develop relevant protective features within the ASFORESEE timespan is detected. Therefore, the equation [1] measures the protective value against rockfall:

[1] $$P_v = \sum_{i=0}^{t} M_i \cdot \frac{1}{(1+r)^i}$$

Where P_v is the protection value of the forest against rockfall risk;

M_i is the difference i between the possible revenues and the expenditures from the forest management incurred in the period comprised between the present (0 in the equation) and the moment t, discounted at the present time adopting the interest rate r.

Option B. In the second option the forest stand is not able to satisfy stakeholders' needs. Nonetheless, since it has a relevant and measurable protective effect, its value is assessed as the reduction in the expenditures needed to build a smaller defensive facility. Its economic value is then estimated as in eq. [2]:

[2] $$P_v = F_s - F_{wf} - \sum_t^0 M_i \cdot \frac{1}{(1+r)^i}$$

Where P_v is the protection value of the forest against rockfall risk;

F_s are the expenditures incurred to build a standard defensive facility, and replace it at the end of its service life, if there was no protective effect by the stand;

F_{wf} are the expenditures to build a smaller needed facility that takes in account the benefits supplied by the forest;

M_i is the difference i between the possible revenues and the expenditures from the forest management incurred in the period comprised between the present (0 in the equation) and the moment t, discounted at the present time adopting the interest rate r.

Option C. when the forest met the stakeholders' need for safety, the option C is adopted, considering the forest as a defensive facility. Hence, the protection value will be equal to the expenditures of the hypothetical facility able to replace the stand and providing the same performances (Spangenberg and Settele, 2010). In a precautionary stance, we integrated this equation a reduction coefficient representing the percentage of blocks stopped by the forest (the ORPI index; see eq. [3]).

[3] $$P_v = (F_s \cdot ORPI) - \sum_t^0 M_i \cdot \frac{1}{(1+r)^i}$$

Where P_v is the protection value of the forest against rockfall risk;

F_s are the expenditures incurred to build a standard defensive facility, and replace it at the end of its service life, if there was no forest;

RPI is the reduction coefficient, between 0 and 1, to return the forest effectiveness to its actual value of effectiveness, equal or lower than the defensive facility designed;

M_i is the difference i between the possible revenues and the expenditures from the forest management incurred in the period comprised between the present (0 in the equation) and the moment t, discounted at the present time adopting the interest rate r.

Avoided Damages approach

Beside these evaluation option, in the last section of the output sheet the user will find the economic evaluation of the forest protection service according to the AD approach. Here only one option is available, since the comparison between the supply and demand of this ES is replaced by the calculation of the value of the assets at risk. The results of this evaluation method consist in a monetary value as well, expressing the amount of damages the presence of the forest allows to avoid.

Once assigned the case study to one of the available options, the economic value of the protection forest against rockfall events is obtained. In this respect, it should be remembered how the protection value is not an exchange value, but rather the translation in economic terms of a service that can be obtained only through a virtuous management of the ecosystem generating it (Laurans et al., 2013). For both approaches, in order to improve the understanding of its measurement and widen its applicability, ASFORESEE expresses the result of the monetary evaluation in several alternative ways. Particularly, the protection ES can be presented as a total value, in € per stand or in € ha^{-1}, or as a yearly benefit, in € ha^{-1} y^{-1}. Even if the last valuation form could lead to some misunderstanding, its adoption its widely spread (Getzner et al., 2017; Grilli et al., 2017) and results to be the most suitable way to communicate with stakeholder, decision-makers and other non-scientific actors for its immediacy and comprehensibility.

Discussions and Conclusions

Coupling the two most suitable method to perform such monetary evaluation, the RC and the AD approaches, allowed to fulfil the aims of the model and to estimate the value of the protection ES of the forest against rockfall. One of the merits of such approaches is to adopt values directly derived from the market prices, minimizing the subjectivity of the evaluation (Paletto et al., 2015). This aspect actually represents one of the most relevant results provided by ASFORESEE: its broad reliance on technical data greatly reduces the assumptions of the user and ensures its wide replicability. On the other hand, some intrinsic limitations of the model still remain, as the substantial difference between defensive facilities and protection forests. Whereas the former can be designed in relation to the safety needs and the specific existing risk; the latter can only be partially manipulated and their performance enhanced, often with negative drawbacks in the short term (Motta and Haudemand, 2000). Moreover, the targeted management needed to improve their protective effectiveness often leads to negative stumpage values. Nonetheless, ASFORESEE does not only take profitable forest interventions into account, rather, it computes the stumpage value of all interventions that should be performed in order to maintain or increase the effectiveness of the forest stand.

Finally, the temporal frame considered by the model represents a relevant variable that may influence its results. The protective function of a defensive facility effectively remains constant in standard environmental conditions during its service life, and then collapses abruptly at its conclusion (Faber and Stewart, 2003). Conversely, the forest stand is characterised by much longer dynamics, and is subject to unpredictable biotic and abiotic disturbances that can temporarily or permanently influence the ES provided (Dupire, 2011). For these reasons, we aim to test the model on different timespans in the future, in order to study the variations in value caused by both the benefits of a dedicated forest management and the increased costs of repeatedly substituting the defensive facility at the end of its service life, which are currently excluded from the evaluation. In a similar manner, the influence on the protective value of the forest resulting from the adoption of different interest rates will also be tested.

To all effects, the definition of different evaluation options reflects the specific conditions a protection forest may encounter, and represents the principal innovative element of ASFORESEE. Obviously, further actions are necessary to put the evaluations generated by ASFORESEE into practice. Among others, the definition of the demand side of this ES could be implemented with a stronger involvement of the stakeholders, and the model could evaluate several gravitational hazards instead of focusing only on rockfall. Further analysis of the elements most highly affecting the output of the model, e.g. via a sensitivity analysis, could also be implemented. Moreover, from a practical viewpoint, only the inclusion of Eco-DRR, such as protection forests, into a risk management strategy at local level would give value to this research and confirm the interest of policy and decision makers to mitigate this natural risk in the most cost-effective way (Accastello et al., 2019; Grilli et al., 2015; Wolff et al., 2015).

The risk mitigation against natural hazards, such as rockfall, is only one of the several ES that society benefits from mountain forests (Gret-Regamey et al., 2012), whose multi-functionality should be enhanced by targeted management, as stated in several national and international regulations (EC, 2013). In this context, our ASFORESEE evaluation model aims to increase awareness, both among scientists and non-academic stakeholders, that, where the protective function is prevailing and perceived as necessary by society, protection forests can represent a reliable, cost-effective and forward-looking Eco-DRR. Similarly, the monetary evaluation confirms that the active management of protection forests can represent a sound investment to be integrated in local risk management strategies, in order to mitigate rockfall risks and ensure the liveability of mountainous areas.

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