PHUSICOS

According to nature

Deliverable 4.3

Integrated digital shared database/platform for monitoring and early warning

Work Package 4 - Technical innovation to design a comprehensive framework

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Summary

Monitoring is relevant throughout the lifecycles of an NBS implementation, including initial baseline monitoring (pre-development conditions) as well as long-term monitoring to assess the impact and efficacy of the NBS on a variety of key parameters. In PHUSICOS, the application of NBS as robust, sustainable and cost-effective measures for reducing the risk of extreme weather events in rural mountain landscapes is the primary focus, and monitoring systems provide critical condition data and support early warning concepts for risk mitigation. An additional aspect of NBS are the opportunities for co-benefits, and monitoring provides documentation and verification of these effects. The engagement of stakeholders in the development and implementation of NBS, i.e. design, implementation, evaluation, monitoring; results in a strong commitment and great confidence in the performance of the project.

This deliverable presents the various components necessary for developing a complementary monitoring network for assessing the performance of Nature Based Solutions (NBS) in the context of the PHUSICOS demonstrator sites and concept cases. These components are essentially the design basis for developing and supplying monitoring systems for NBSs. This deliverable also demonstrates the application of the Living Labs (LL) concept to further develop design concepts into a detailed monitoring system design.

The first part is a guideline covering conceptual design considerations and thus is essentially a working reference for organisations planning on implementing monitoring of NBSs. The monitoring needs have then been defined for each ambit, providing for each indicator the methods, sensors, and data that can used. Each of these are subsequently described, highlighting the advantages and drawbacks of them. Technologies presented include both tried-and-true technologies as well as state of the art.

The second part demonstrates the application of the LL concept, showing how stakeholders and experts may work together to refine design concepts and general recommendations into detailed monitoring system designs in preparation for procurement and implementation. The Serchio case study is used as a test case for a modified LL method appropriately adapted to conform to COVID19 restrictions through the use of online methods. A tailored online questionnaire was used to gather data from stakeholders, and the results from the survey have been collated and interpreted. This modified LL is planned to be applied to all the PHUSICOS sites described within this report.

The document concludes with general features and recommendations for implementing a monitoring networks as well as for the specific challenge of designing an early warning monitoring system.

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1 INTRODUCTION

The global objective of the PHUSICOS project is to demonstrate how nature-based solutions can reduce the risks related to hydro-meteorological events in mountainous and rural contexts.

Evaluating the performance of the NBS for aspects like engineering performance, positive environmental impacts, promoting socio-economic co-benefits and other factors are essential for documenting the ability of NBS to fulfil this objective. Indeed, the evaluation of the performance of NBS, at short and long terms, as well as the co-benefits, are necessary to convince and foster the use of them (Rizvi et al., 2015; Runhaar et al., 2018). McVittie et al. (2018) indicate that monitoring and research are essential priorities.

The engagement of stakeholders in the various processes necessary, including development of monitoring systems, will result in a strong commitment and great confidence in the performance of the project.

1.1 Scope of Task 4.3 and Deliverable 4.3

The objective of T4.3 is to develop, with stakeholders and experts, a complementary monitoring network for demonstrator sites and concept cases. The following actions are needed:

- Identify key parameters and needs for data collection;
- Share knowledge with stakeholders;
- Create and supply a monitoring and early warning system if necessary.

The scope of Deliverable D4.3 is to develop the design concepts (e.g. design basis) for developing and supplying monitoring systems for NBSs and testing how the living labs concept may be used to further develop design concepts into a detailed monitoring system design.

This deliverable will provide guidelines and recommendations for detailed planning, procurement and deployment of monitoring systems by the owners of NBSs in WP2.

The following topics will be considered when developing the design concepts:

- What is the purpose of the monitoring system: definition of Baseline monitoring, long-term monitoring, early warning
- What data is needed, and why (Identifying parameters to be monitored)
- How to monitor these parameters (sensor, monitoring design)
- How to process data (process, modelling)
- How to make data accessible (How and which monitoring data can be shared and used with stakeholders).

This first part of this deliverable will be a guideline covering conceptual design considerations - essentially a working reference for organisations planning on implementing monitoring of NBSs. As a practical approach to this, monitoring needs will be considered in terms of 5 ambits identified by the Assessment Framework Tool developed in Task 4.1:

- Risk Reduction
- Society
- Local Economy
- Technical & Feasibility Aspects
- Environment & Ecosystems

The second part of the deliverable will focus on the application of the living labs concept when preparing detailed plans for monitoring systems.

Finally, some general features and recommendations are proposed for implementing a monitoring networks. For designing an early warning monitoring system, some general features and recommendations can be made.

1.2 NBSs performance monitoring: State-of-the-Art (SOA)

1.2.1 Introduction to SOA in NBS monitoring

To monitor the NBS implementation process, different types of criteria must be measured, covering a large range of topics (Kabisch et al., 2016 and Raymond et al., 2017). Assessment of the indicators can be qualitative, quantitative, or mixed (Raymond et al., 2017). This assessment can be based on direct measurements, modelling, or the combination of these. Note though that monitoring may also address qualitative variables that are not possible to quantitatively measure, for example improving aesthetics; or are difficult to measure using simple sensors, for example increasing biodiversity.

Some potential barriers are reported by Raymond et al., 2017. Indeed, in some cases, the benefits of NBS are measured with a lot of uncertainty, particularly among certain urban stakeholders, such as urban planners and decision-makers (Kaczorowska et al., 2016). Moreover, timing and financial aspects may add difficulties in realising the monitoring (Baur et al., 2013; Hansen et al., 2015; Kabisch, 2015), with uncertainties related to the duration of the monitoring.

One aspect of monitoring is the collection of parameters (measurements) for specific variables of interest. These may be any measurable quantity, for example soil moisture, temperature, water level, ambient noise... nearly any physical quality or quantity relevant for evaluating or assessing whatever system is being measured.

Monitoring is a long-term process as it is necessary to quantify some indicators during all the NBS implementation process (Raymond et al., 2017).

1.2.2 Sensors and networks: IoT technology

Measurement systems previously have been dedicated installations, consisting of sensor or instruments, connected to power supplies, data logging facilities or alternately communication of data to a central collection and processing facility. Internet of Things concepts has changed this paradigm.

IoT is a suite of technologies and applications that equip devices and locations to generate all kinds of information - and to connect those devices and locations using the internet backbone for communication. Ideally data is available for instant data analysis and action. A significant driver for IoT development that is familiar to everyone is home automation.

IoT is primarily built on standard protocols and networking technologies, where the major enabling technologies NFC (near-field communication), LTE-A (cellular), low-energy variants of Bluetooth, WIFI, and radio protocols (LoRa). Generally individual devices will operate through a gateway device, interfacing the local IoT nodes based on low power networking technologies with the internet.

While the underlying specific protocols and technology are not of specific importance for implementing NBS monitoring, the overarching philosophy of deploying a monitoring system implementing IoT is relevant. The distinct advantage is that the IoT approach provides flexibility and scalability - once an IoT portal is in place additional sensors and instruments can be easily added and configured as needed or wanted. Data is handled through the portal and into an internet-based service for data archival and processing.

To understand this, consider the direct analogy to consumer use: a 'smart home' system. Once a consumer has installed the 'smart home' hub, it is simple for them to expand the system with IoT devices like lights, switches, video systems, smart home speakers etc. In our case we would envision a 'smart NBS' hub, where the local stakeholders can implement IoT based measurements relevant for their needs and interests, communicating the data through the local NBS portal to some form of central data archival (likely a cloud-based service).

1.2.3 Automation of data collection and processing

Ideally the collection of data / measurement of parameters should be implemented in the most cost-efficient way. Manpower is a significant cost, and implementations of monitoring systems need to consider the potential for cost savings by automating data collection and reducing the need for active follow up / measurements by persons in the field. Automated data collection is an inherent feature in the IoT approach.

1.2.4 Cloud based services and advanced processing/analysis

Cloud-based services is a general term describing IT resources provided over the internet. Such services can come via public or private clouds. Public clouds are provided by commercial vendors, for example Amazon Web Services, Microsoft Azure, Google Cloud and many others. Private clouds are owned and operated by an organization, usually accessible only to the employees or associates to the organization.

There are three main service models of cloud computing

- Infrastructure as a Service (IaaS). This is the basic category, and is where the user rents IT infrastructure, for example servers and virtual machines (VMs), storage, networks, and operating systems on a pay-as-you-go basis.
- Platform as a Service (PaaS). This category provides an on-demand environment for developing, testing, delivering, and managing software applications. This is the domain where artificial intelligence and machine learning processing routines are developed and implemented.
- Software as a Service (SaaS). This category provides software solutions over the internet, typically as a subscription or pay-as-you-go service. The cloud provider hosts and manages the software. Major software suppliers are adopting this, for example Adobe Creative Cloud is a SaaS, as is Google Documents and recent implementations of Microsoft Office.

In the NBS monitoring context, any of these services (or combinations of them) may be relevant for a specific installation. This will be dependent on the interests and needs of the organization implementing the NBS. Quite likely, most installations will utilize a SaaS scheme where a proprietary data collection software manages an archival databased, provides tools for plotting and presenting data, and basic analysis tools such as statistics and extrapolation.

Big data is a collective term for analysing or extracting information from data sets that are too large to be processed using traditional analysis software. Data may be high in volume (many examples of a specific kind of data) or high in complexity (many attributes associated with a type of data). There are numerous challenges related to big data: data storage, analysis, search, visualization, querying, etc. One (of many) application areas for big data is user behaviour analytics, for example identifying use patterns and trends.

Machine learning is a subset of Artificial Intelligence, where in the simplest context the idea is that learning model(s) implemented in a processing software enables the software to select and adapt rules describing behaviour or patterns in the data. The learning models are generally:

- Supervised learning: The learning algorithm is given labelled data and the desired output, and the software identifies rules relating the data to the output.
- Unsupervised learning: The learning algorithm is given unlabelled data, and the algorithm identifies patterns in the input data.
- Reinforcement learning: The algorithm interacts with a dynamic environment that provides feedback in terms of rewards and punishments.

The implementation of a traditional monitoring system (based on IoT) will generally focus on an identified set of indicator parameters, producing well-structured data in relatively small volumes. This data will likely be suited to traditional analysis and processing, e.g. big data and machine learning disciplines will probably not be involved. However, monitoring in a broader sense may incorporate more general variables, such as public use patterns or public approval over time. These variables may be assessed through indirect variables or methods, for example numbers of internet searches addressing features or aspects related to the NBS, numbers of photos posted in social media etc. These data sources may be more relevant for big data / ML approaches

1.2.5 Remote sensing techniques

Remote sensing techniques detect and monitor various physical characteristics of an area by measuring reflected and emitted radiation from a distant measurement platform, for example from a satellite or from an aircraft, but in some cases the measuring platform may be a ground-based stationary position or a light mobile platform like a drone or a small vehicle.

The measurements are taken by special devices, for example laser scanners, optical imaging (visible and near-visible wavelengths), electromagnetic sensors or radar systems deployed on the measuring platform.

An advantage of satellite-based measurements is that the systems are already deployed and are collecting data, thus data archives will likely yield historical remote sensing data from any site. The amount of data available, and the type/nature of the data will vary significantly from location to location. The cost of the data depends primarily on the application, type of data, resolution, and the satellite mission producing the data.

Some examples of technology employed:

OPTICAL IMAGING: Essentially a high-resolution camera producing high quality images. Variations of this include panchromatic, multispectral and hyperspectral cameras, producing high quality images in various bands of wavelengths of light. Optical images may be used for change detection to monitor processes, for example erosion, agriculture, land use changes etc. Utilizing the multispectral data adds additional opportunity: Different wavelengths interact uniquely with the reflective surface, and by combining images obtained in various wavelengths it is possible to map changes in the reflective surface. For example, various vegetative indices may be developed from multispectral imaging allowing the identification of plant health. The NVDA index uses. A disadvantage of optical imaging is that it is limited by anything affecting visibility, for example cloud cover or low light. High quality cameras can be easily deployed using consumer grade drones.

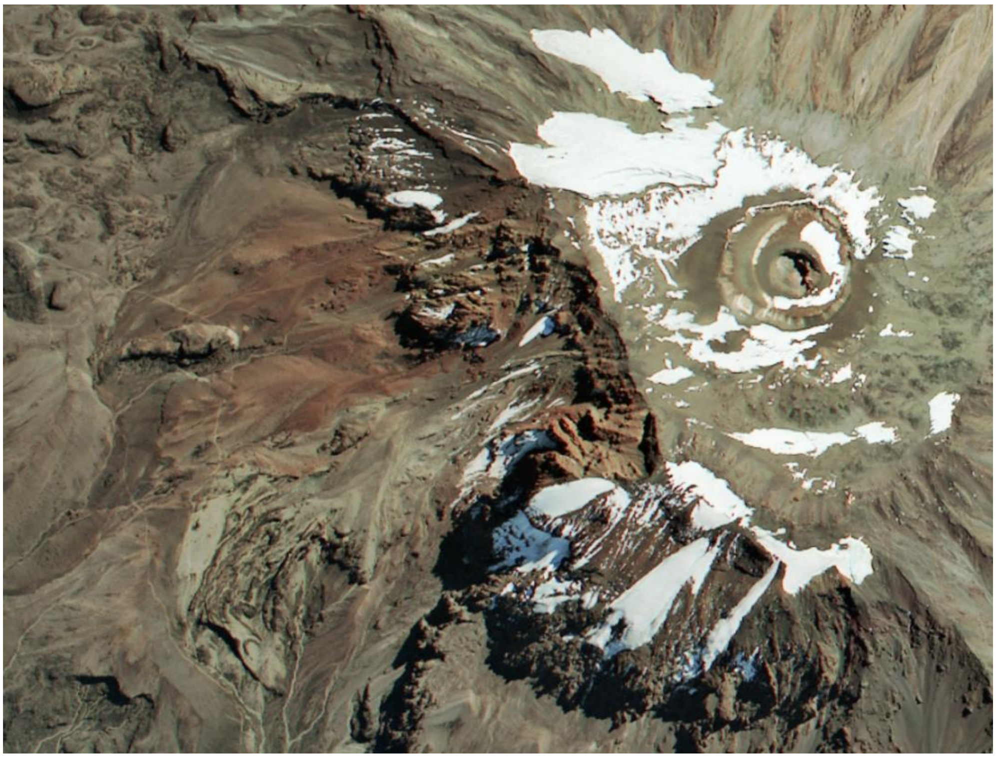


Figure 1. High resolution satellite based optical image of Kilimanjaro. Source: Airbus Defense & Space. High resolution images may also be collected using cameras carried by small drones.

LIDAR: A method for measuring distances (ranging) using a laser and measuring the reflection with a sensor. The distance between the target point and the sensor is calculated through the travel time and changes in wavelengths. 3-D representations can be created by scanning large areas. National and international LIDAR missions have for example created base digital terrain maps for the earth surface. LIDAR can to a certain extent 'see' through a forest canopy, provided the vegetation is not too dense. The method produces an enormous number of measurement points, and a certain percentage of these manage to pass through the leaves and reach the ground surface. Lidar systems are typically larger and heavier, requiring deployment from a suitable aircraft (helicopter or fixed wing plane), or if drone deployed requiring commercial grade drones with substantial lifting capacity.

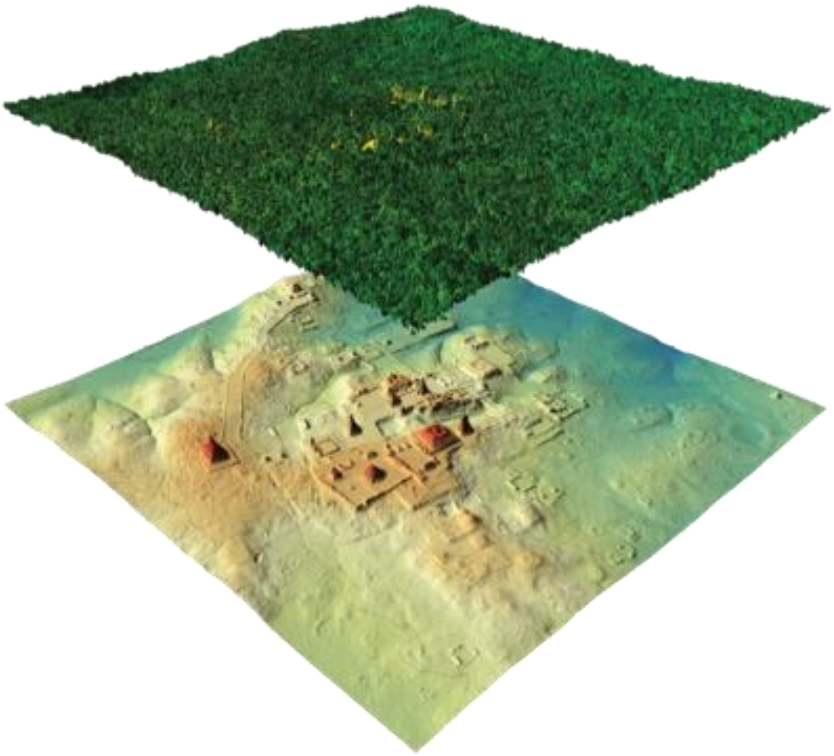


Figure 2. Example of LIDAR imaging. Image reference: Airborne Lidar for Archaeology in Central and South America - LIDAR Magazine (lidarmag.com)

RADAR IMAGING: Electromagnetic waves issued from a transmitter reflect on a surface or object, and a receiver records the reflected waves giving information about an objects location, and through the Doppler effect changes in wavelength are used to measure velocity. For earth observation applications, synthetic aperture radar (SAR) systems are the most relevant, as the SAR implementation improves spatial resolution which is necessary when imaging from a satellite.

Radar systems can be ground-based (fixed), carried by aircraft or deployed on satellites. Radar systems are currently too large for consumer grade drones, if deployed on a drone platform these would require a commercial grade drone with sufficient lifting capacity. Radar sensors utilize longer wavelengths (centimetre to meter scale), which gives it the ability to see through clouds, or through the canopy foliage in a forest to image the ground surface. Radar systems utilize various bands (for example X, C, L, and P) corresponding to ranges of frequencies, and associated typical applications. Information regarding polarization and scattering of the radar signals are also important for interpreting the radar imaging data.

Table 1: Characteristics of different radar systems

Band	Frequency	Wavelength	Typical Application
X	8 - 12 GHz	3.8 - 2.4 cm	High resolution SAR (urban monitoring; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 - 8 GHz	7.5 - 3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2 - 4 GHz	15 - 7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1 - 2 GHz	30 - 15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3 - 1 GHz	100 - 30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

(Table source: NASA tutorial; https://earthdata.nasa.gov/learn/what-is-sar)

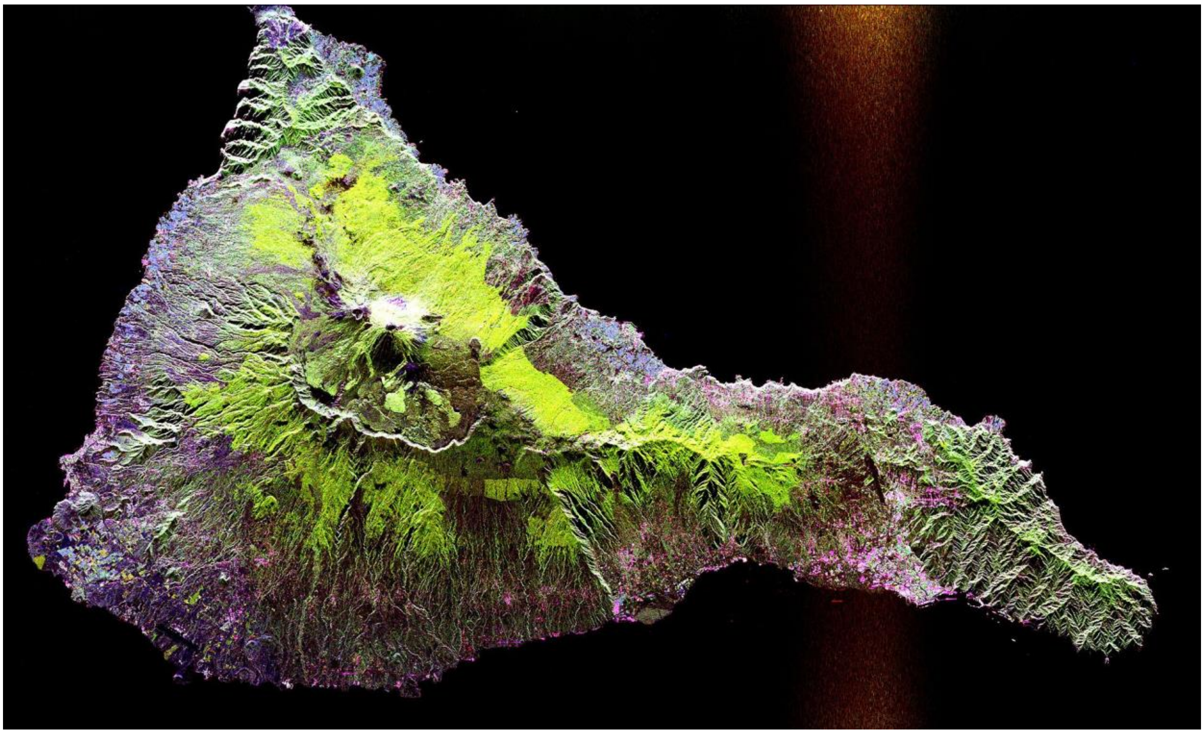


Figure 3. Radar image of Tenerife Island. This radar image acquired by the SIR-C/X-SAR radar on board the Space Shuttle Endeavour shows the Teide volcano. The city of Santa Cruz de Tenerife is visible as the purple and white area on the lower right edge of the island. Lava flows at the summit crater appear in shades of green and brown, while vegetation zones appear as areas of purple, green and yellow on the volcano's flanks. Credit (Image and text): https://en.wikipedia.org/wiki/Synthetic-aperture_radar media/File:TEIDE.JPG.

Interferometric SAR is a processing technique where multiple images (stacks) over an area are inter-processed to identify changes in distance between the transmitter and the reflective surface between successive SAR images. By comparing the images, the phase information in the SAR signals produce interferometric effects allowing the calculation of changes in distance. This approach can be used for mapping of subsidence or ground movements. An advantage of this technique is the existing data archives: it may be possible to 'go back in time' and calculate subsidence or changes in an area prior to implementing any activities.

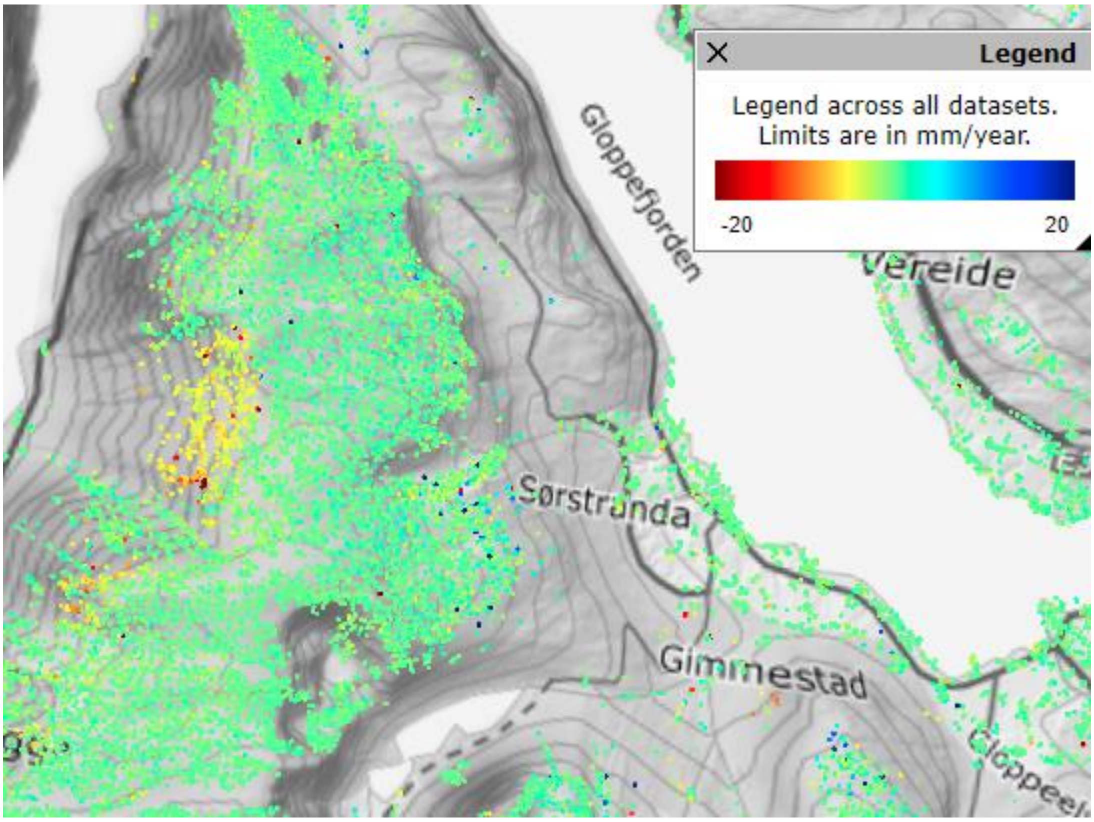


Figure 4. Vertical movements from InSAR data. Screen shot from the insar.ngu.no website, showing publicly available InSAR data. Processed to show vertical movements along a Norwegian fjord

2 PRESENTATION OF DEMONSTRATION SITES

2.1 Serchio River Basin, Italy: buffer strips

2.1.1 Site description

The Serchio river basin is defined as a basin of national interest according to Italian legislation and has been identified as a "hydrographic district" for the implementation of the Water Framework Directive (2000/60/EC) and has an area of 1,564 km^2. In the lower part of the Serchio river there is the sub-basin of Lake Massaciuccoli (surface about 13 km^2) with a hydrographic basin of 114 km^2 and with a hydrogeological basin of 170 km^2. The lake has an average depth of about two meters and is partly delimited by embankments that develop for a length of about 16 km and reach a height of about 0.60 meters above sea level. The few natural watercourses that feed the lake come mainly from the eastern hills at the foot of which the body of water is located, while the inflows coming from the various reclamation channels both to the north and to the south have a greater impact.

The territory has been characterized since the beginning of the twentieth century by a strong process of agricultural conversion and urbanization mainly concerning Viareggio and Torre del Lago. The basin falls within the MSRM Natural Park as well as several protected areas of international and national importance (SPA, SIC, NATURA 2000, RAMSAR). Challenges in the basin include extreme drought, floods, water pollution, adaptation to climate change, agriculture and seismic risk. ADBS is conducting efforts to address these risks throughout the basin and in particular in the Lake Massaciuccoli area, through the design and implementation of NBS measures funded by the EU, the Ministry of the Environment and Protection of the Territory and the Sea and the Tuscany region.

The implementation of NBS measures will be useful for increasing the resilience of the territory, mitigating the effects of climate change, improving water quality with direct effects on biodiversity and ecosystems. Specifically, buffer strips, cover crops, gentle management of canals and sediment retention basins are being implemented. ADBS collaborates with stakeholders to develop the implementation of NBS measures, including maintenance and monitoring plans and explore planning strategies with the overall aim of developing an ecosystem management approach for hydrogeological risk reduction in the Lake area by Massaciuccoli.

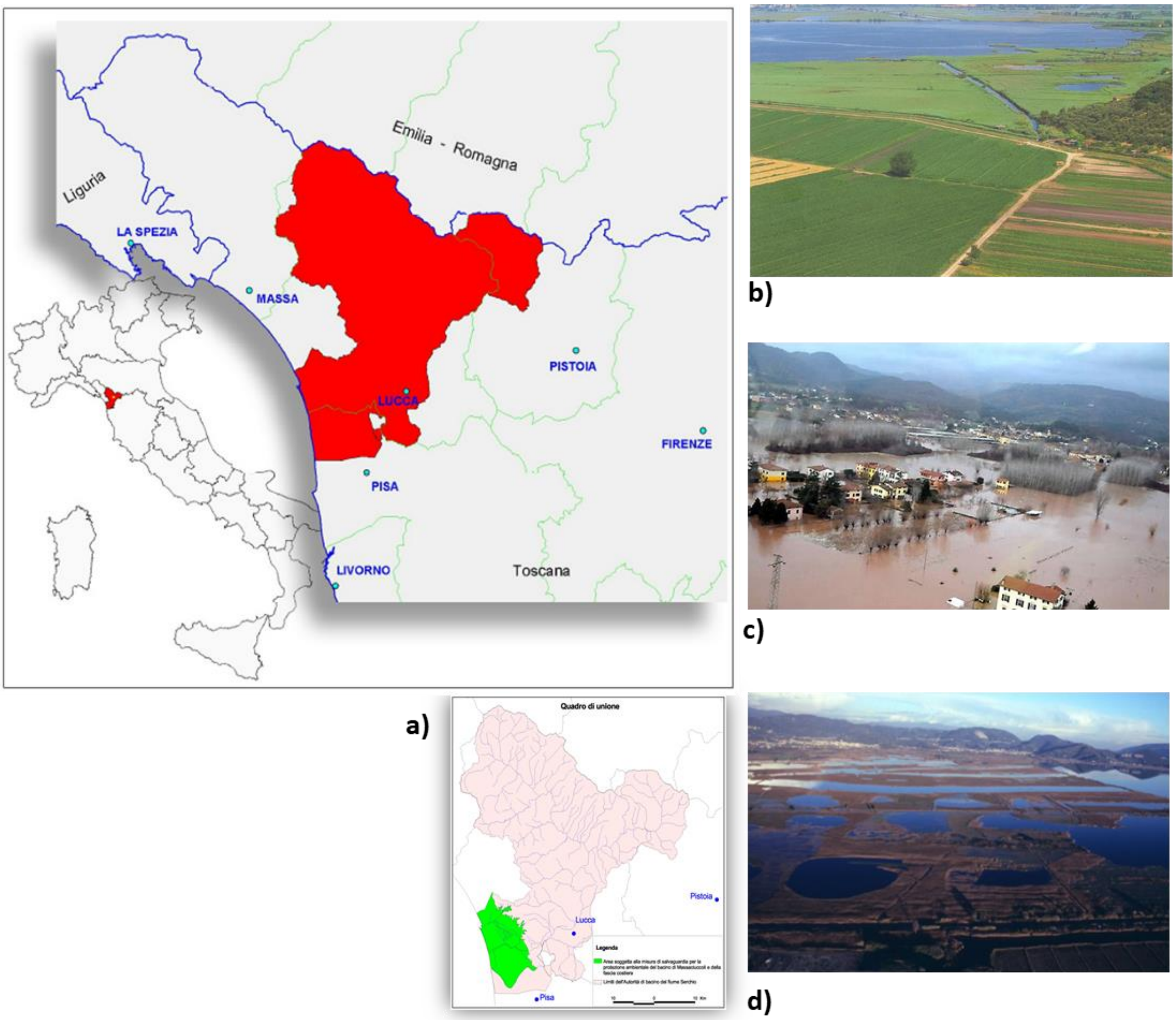


Figure 5. Massaciuccoli Lake. a) Massaciuccoli's lake area location; b) Massaciuccoli's lake area; c) Massaciuccoli's lake area during the flood of December 2009; d) Massaciuccoli's lake area during the drought of July 2017

2.1.2 Description of the Nature Based Solution

The NBS implemented are buffer strips. Buffer strips are vegetated areas consisting of perennial herbaceous strips and / or arboreal and shrub species placed at the edge of the cultivated fields. They aim to mitigate the risk of runoff of potential contaminants or pollutants from agricultural lands to the water bodies, which can damage the ecosystem and fauna activities. The main functions of the buffer strips are to provide a barrier and to increase the permeability of the soil along the channel bank. In this way the runoff water is intercepted by the vegetation and infiltrates into the soil before flowing into the water body. Furthermore, the face pads act positively in the retention of eroded soil particles and play an important role in maintaining biodiversity and diversifying the agricultural landscape.

The buffer strips will be implemented along the tertiary channels located between Fosso Boccalli and Fossa Nuova Channel, in the south-east part of Massaciuccoli's area. It is worth financing this measure because as NBS it only includes the use of natural materials and it achieves several objectives simultaneously:

1) reduction of the consumption of soil,
2) reduction of pollutants washed away from the cultivated areas to the waterways,
3) short implementation time,
4) effectiveness in the short and medium term, and
5) simple maintenance.

Not least the measure is perfectly integrated with the environment of the Massaciuccoli area belonging to the area of great natural value of the Park of San Rossore Massaciuccoli (SIC, SIR, ZPS, Ramsar).

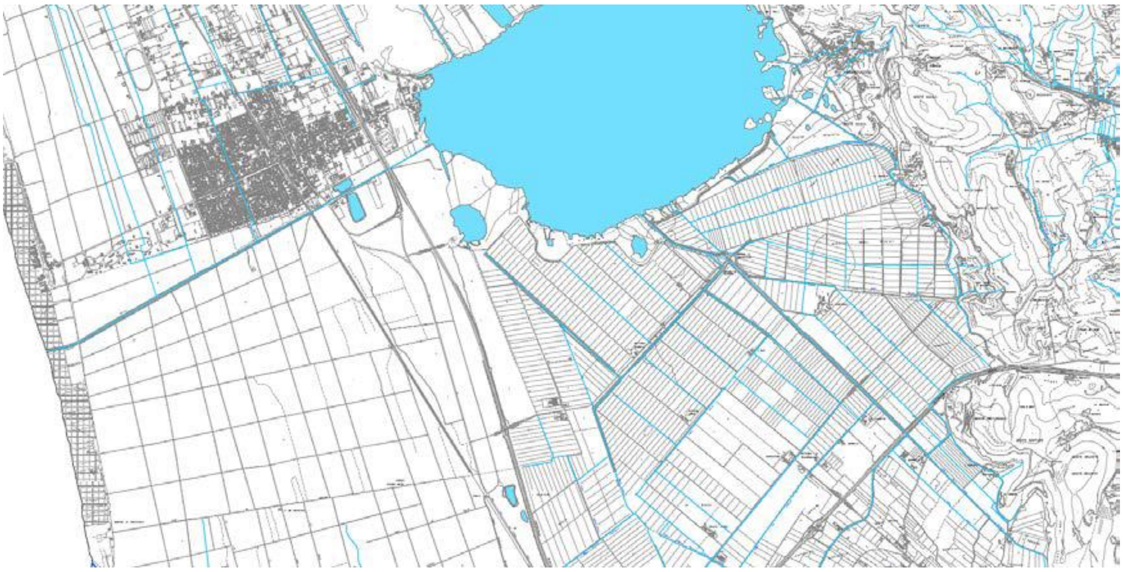


Figure 6. Overview of the intervention's area

Figure 7. Channels in the intervention's area

2.1.3 General assessment and needs by ambit

Risk reduction
PHUSICOS D2.1; Chapter 4.1.2

The realization of the buffer strips will contribute to the control of surface erosion and this will lead to a reduction of solid transport into the waterways, reducing the possible overflows with a consequent increase of the hydraulic resilience of the territory, favouring the actuation of the Water Framework Directive (2000/60/EC) and of Floods Directive (2007/60/EC).

Technical & feasibility aspects
(PHUSICOS D2.1; Chapter 4.1.3)

The NBSs compared to grey solutions have the great advantage of integrating perfectly and definitively with nature, improving the environmental conditions. This aspect is very important because they do not need to be dismantled and disposed of after the end of life.

NBSs can be made with instruments, machines and methods that are minimally invasive and require reduced maintenance, which can be easily achieved with agricultural tools. This makes their maintenance faster and cheaper. In fact, the full effectiveness of the buffer strips can only be achieved by providing for their periodic maintenance. In the case of herbaceous bands, it is necessary to make regular cuttings to avoid an excessive development of the vegetation. Depending on the species, this may be needed annually or even more often. In addition, the buffer strips must remain as neutral as possible, so no fertilizers or plant protection products must be applied on the area as well as the grazing for animals must be avoided. To preserve the best water infiltration conditions in the deep layers of the ground, it is also necessary to limit compaction of the soil and the subsoil, avoiding the transit of the operating machines on the grassy strips. There are three maintenance phases:

1. Plants maintenance: the first maintenance is carried out on the immature plants, possible splitting of the twigs or the root system, the first watering, the fertilization of the hole, the laying of a brace. In the sowing phase, with small seedlings, the use of a mulching tissue for the control of weeds is generally recommended;
2. Intensive maintenance: it is carried out in spring after sowing operations. The main operations consist in emergency irrigation (if present) and in the containment of weeds to protect the young seedlings from their competition, ensuring the best development up to the achievement of self-sufficiency and complete affirmation on the ground and the flora in competition;
3. Extensive maintenance: it follows intensive maintenance and involves maintenance operations of already established plantations and their care to control their overall development, including pruning and possible reintegration/restorations of dead plants.

Environment & ecosystems

Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the environment:

The implementation of the buffer strips will slow down the process of leaching and transferring pollutants from the agricultural land to the lake, improving the ecological status of the lake ecosystems and the surrounding areas favouring the return of animal species and biodiversity. Moreover, using natural materials instead of grey solutions gives an additional benefit to the environment and benefits the beauty of the landscape.

Society

Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for society:

The improvement of this measure will also contribute to the control of surface erosion, subsidence, and reduction of solid transport in the channels. All together these actions will increase the overall hydraulic resilience of the territory, favouring:

1. the surface water outflow;
2. the increase of water quality and quantity for the farmers and all activities in this area;
3. the implementation of the measures of "Water Management Plans" and of "Flood Risk Management Plan", and thus reducing the risks conditions also to human life.

Participatory process (PHUSICOS D2.1; Chapter 4.1.7):

Two Living Lab (LL) events have been hosted during which the NBSs were analysed and some proposals were made from the stakeholders. The following attendants were present during these events: Regione Toscana, Consorzio di Bonifica TN1, Comune di Massarosa, ARPAT, Autorità Idrica Toscana, Univerità di Pisa (Dip. Sc. della Terra, Dip. Sc. Agrarie, Alimentari e Agro ambientali), Scuola Superiore S. Anna, Università di Firenze (Dip. Ing. Civile e dell'Ambiente) and other associations like Coldiretti, Legambiente, LIPU, Rete Ambientale Versilia, Amici della Terra, Comunità Interattive, Associazioni Le Nostre Radici.

At the first LL it was proposed to replace the "buffer strips" with the "banks vegetation" or to implement the cover crops. Subsequently, the participants agreed on the fact that the buffer strips were less expensive and easy to implement and maintain, still achieving the same objectives. Upon indication of the associations, the buffer strips with a width varying from 1 to 3 m were proposed to achieve the objective without going against farmers` needs (in this way the overlap with the cultivated areas was reduced to facilitate maintenance by mechanical means). In addition, it was proposed to cover the canal slopes with grass to limit erosion in the canals.

From the second LL it emerged that the participants would like to create an area of experimentation in which to evaluate the effectiveness of the buffer strips on the three orders of channels. To meet their wishes, the proposal includes buffer strips on primary, secondary and tertiary channels and a monitoring system to better understand the effectiveness of the bands. The area is about 30 ha and the overall length of the channels on which to intervene is about 14.5 km.

Based on the previous suggestions, from the comparison with local experts, agricultural associations, departments of the University of Pisa such as the DST (Geological Department) and the DSAAA-a (Agricultural Department) it emerged that the width of the buffer strips to be realized can vary from 1 - 3 m instead of from 1-10 m as originally planned. This technical aspect makes their implementation and maintenance easier and the intervention economically sustainable.

Local economy

Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the local economy:

The improvement of the quality conditions of the water resource, the ecological status and the whole ecosystem will have an impact on the social condition and the economy of the area as areas currently discarded and not usable by the community can be recovered with an economic benefit for the local associations (bird watching, kayaking, etc.) determined by the greater influx of customers and for citizens who can spend more time safely near the shores of the channels.

2.2 Gudbrandsdal, Jorekstad, Norway

2.2.1 Site description

The valley of Gudbrandsdal is one of the most populated valleys in Norway, and the flood plains along the river are extensively used as farmland. Villages, roads and railways are also largely down in the valley. Many settlements are situated along the river. This due to the lack of other available land.

The area is highly susceptible to flooding. The most common flood generating processes has been snow melting. Lately this have been changing, and we have seen reduced snowmelt floods and more floods caused by heavy rainfall.

In 2011 and 2013 there were two large floods in the valley caused by heavy rainfalls combined with snowmelt. The floods have caused considerable damage to agricultural land and infrastructure situated along the river.

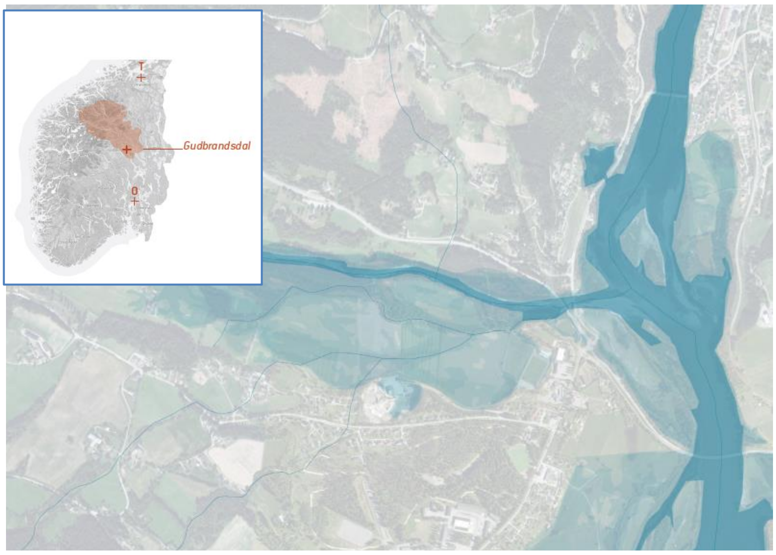


Figure 8. Valley of Gudbrandsdal location

Figure 9. Valley of Gudbrandsdal area

Figure 10. Oppland County during flooding (Credit: all photos from Gudbrandsdal/Oppland county by Heidi Eriksen and Turid Wulff Knutsen)

2.2.2 Description of the Nature Based Solution

The proposed measure is to remove the existing flood protection along the riverbank and build a new green flood barrier further away from the river. This barrier will be built using only natural and local materials. The Jorekstad area consists of housing, infrastructure, agricultural land, and a relatively large sports facility with football fields and a swimming hall. The new flood barrier will be approximately 2300 meters long and is to be located between the agricultural land and the forested floodplain (Figure 1). By placing the flood barrier here, it will protect houses, agricultural land and the football fields from flood damage, while the area closest to the river will be frequently flooded and get an increased value as a wetland. Consequently, the measure will lead to a higher security for the society, and at the same time have a positive effect on the natural environment and the ecosystem in and close to the river. It will also allow the river to expand during flood situations, creating both a river course with high water capacity, and room for natural processes in the watercourse.

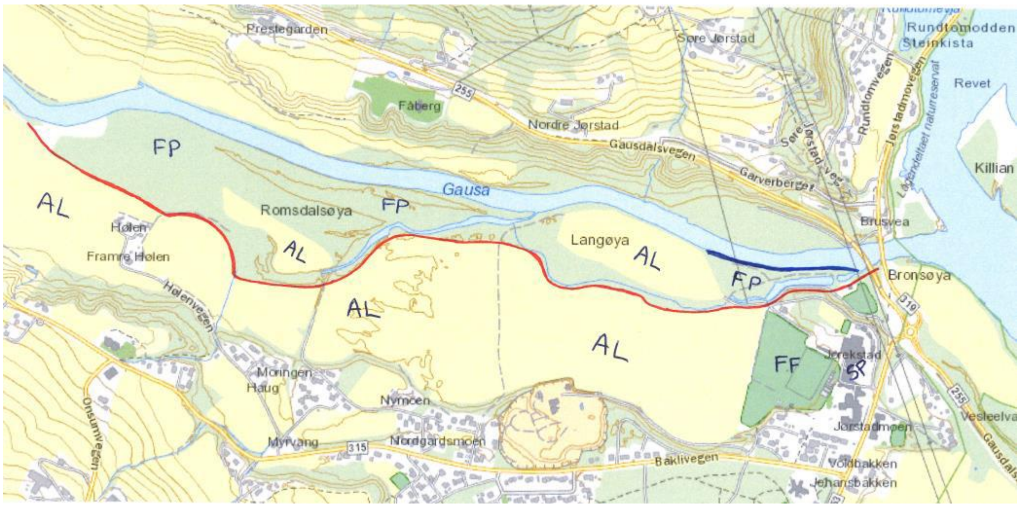


Figure 11. Map of the Jorekstad area. Red line: The location of the proposed flood barrier. Blue line: Existing flood preventing measures/erosion protection of the riverbank along the river Gausa; this is suggested for removal. AL = Agricultural land. FP = Floodplain. FF = Football fields. SP = Swimming pool (indoor).

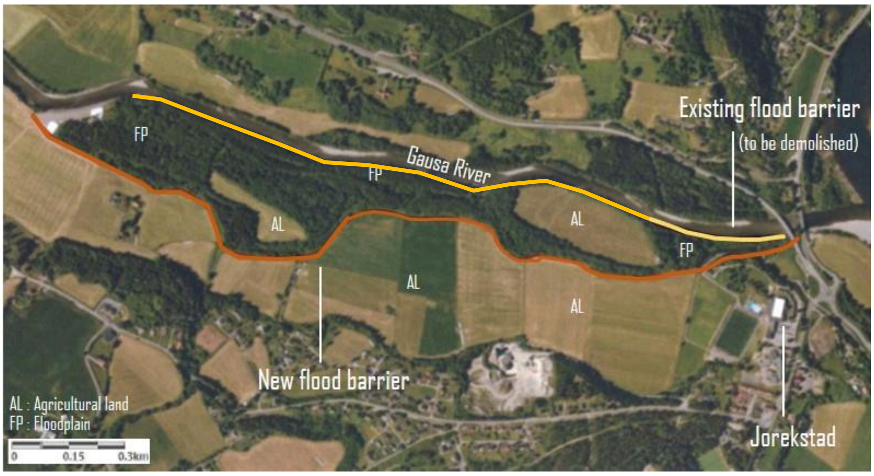


Figure 12. Jorekstad current situation and proposed barrier (Orange line)

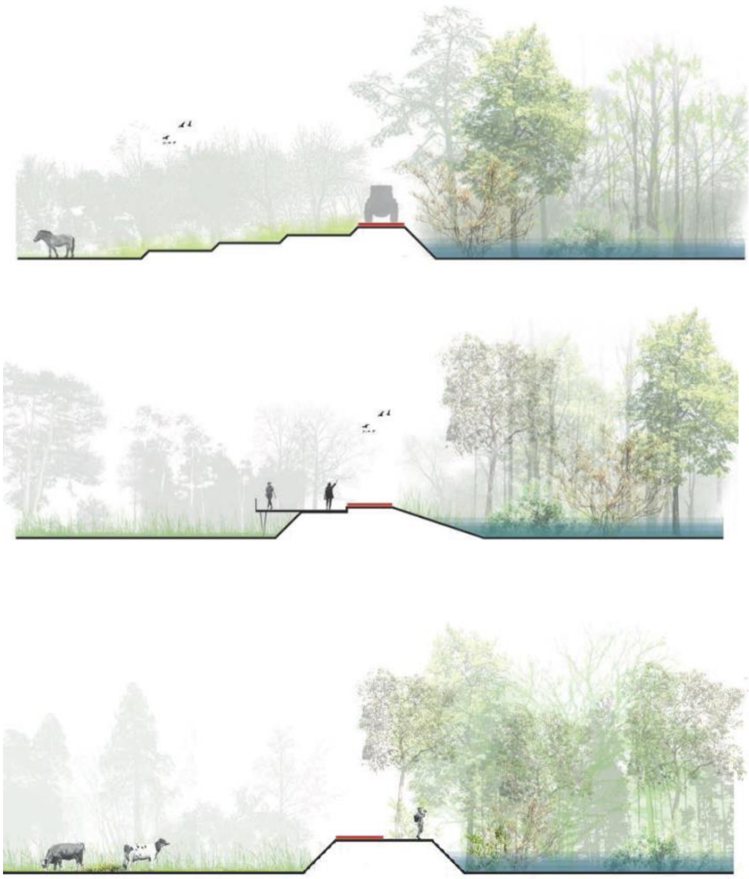


Figure 13. Jorekstad NBS: Landscape architects' design concepts (AgenceTer, France)

2.2.3 General assessment and needs by ambit

Risk reduction
PHUSICOS D2.1; Chapter 4.1.2

The measure will prevent flooding of a large area and lead to increased safety for residents and users of the sports arena, including many children.

Regarding economic values, there has been done a cost-benefit analysis based on the damages after the flood in 2013. For agricultural land, the estimated savings are 189 000 Euros. A lot of the agricultural land in this area is deemed as high quality, and the benefit is therefore relatively high. For the sports arena, the estimated savings are 4.2 MEUR.

This calculation assumes six flood events with the same scope in the next 80 years but does not include the climate change perspective with increased precipitation and more frequent large floods, and smaller floods which happen more often. It is therefore believed that the estimate for savings is conservative for the sports arena. With regards to infrastructure it has not been done a concrete estimation of the potential savings, but in general infrastructure is a very costly sector, so the measure is expected to contribute to savings also here.

The measure will also have a positive effect on the ecological state in the area. Two football fields in the sporting arena are covered with artificial grass and therefore contains a lot of micro plastics. During a flood event, large amounts of these plastic fragments end up in the river. Also, frequent flooding of the agricultural land leads to run-off of nutrients, such as phosphorous and nitrogen into the river, with reduced water quality as a result. For several years there has been taken water samples from the river Gausa, which has been analysed for total phosphorous and total nitrogen. In accordance with the classification system of the EU Water Framework Directive, the river Gausa has a moderate ecological status regarding total phosphorous, and a poor state when it comes to total nitrogen. Diffuse run-off from agricultural land is a factor of influence and contribute to organic pollution of the river. The run-off can also affect the quality of the agricultural land by making the soil poorer in nutrients, and thereby inhibit agricultural processes. By placing the flood barrier on the proposed location, it will prevent both micro plastics and other substances ending up in the watercourse.

For the social situation, mitigating the flood risk will cause the society to be better equipped in handling meteorological events. Reducing the damages on housing and infrastructure will also increase the general well-being of the citizens and society.

Effectiveness (PHUSICOS D2.1; Chapter 4.1.5)
The measure will have a great impact in the long-term; in terms of restoring the floodplain, protecting the agricultural land, and enabling the safe use of the sports arena. The location of the barrier will allow the river to expand during flood situations. The measure will therefore be effective during larger floods and considers changing flood volumes in the future. However, one needs to keep this in mind when dimensioning the barrier.

Also, by receding the barrier, it will be less vulnerable to erosion, and hopefully it will be less need for maintenance. There needs to be a plan for maintenance by Lillehammer municipality, who has confirmed that they will take responsibility for the measure once it has been implemented. At a minimum, the measure must be inspected after each flood event, potential damages must be documented, and the damages must be repaired before the next spring flood.

Technical & feasibility aspects
PHUSICOS D2.1; Chapter 4.1.3

The measure is proposed in the Lågen plan. Therefore, the proposed green flood barrier has been evaluated using hydraulic models and the results have been included in a consequence evaluation. This lays a good foundation for further detailed design and construction of the measure.

The hydraulic model has considered different flood sizes in relation to height of the barrier and the consequences of a barrier on flood water levels. The hydraulic model contains information such as cross profiles of the river, laser scanning of adjacent land areas, depth mapping of the river, hydrological data, sand- and gravel deposits in the watercourse, and constructions in the river such as bridges and dams. The reliability of the knowledge regarding flood preventing effect and the consequences of building a flood barrier in this area is therefore high.

There is, however, still a need to do a detailed design of the barrier itself. This in terms of shape, type of mass to be used, erosion protection, and re-vegetating. While engineers will be involved in the technical design of the measure, we also see a need for input from landscape architects to ensure that the barrier sits well in the landscape. The intention of the measure is to be effective, but also that it fits well into the surrounding areas. For this, there is a possibility of using one of the PHUSICOS partners, for example AgenceTER, at least for a preliminary planning. However, for the detailed planning, one must bear in mind the requirements of public procurement. Thus, any advice from PHUSICOS partners must be done and incorporated before the procurement is made.

The measure needs to go through a public procurement process nationally. We propose that we apply an innovative public procurement process, in which we hope to encourage local resources to get involved. Since PHUSICOS has explicitly emphasized that local job creation is an important goal in the project, encouraging local resources is a way to help ensure this. It might take a little longer time, but the potential reward would be well worth it. Oppland County has been in a dialogue with Lillehammer municipality, and they are very positive to the project, but would like the County to take the driver's seat with regards to the procurement process. Oppland County is ready to take this responsibility, in dialogue with both the Confederation of Norwegian Enterprise (NHO), Lillehammer Municipality, and perhaps also the sports club and Jorekstad swimming hall.

Once the detailed design has been done and the procurement process is fulfilled, it is believed that the measure can be implemented relatively quickly, realistically during 2019. The green flood barrier is going to be built in dry, flat land, and therefore technically relatively easy to implement.

Less maintenance costs: By receding the green flood barrier, the water will hopefully not inflict so much damage, thereby reducing the need for maintenance.

Environment & ecosystems

Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the environment:

Excluding the need for other intrusive measures: Several measures to prevent flooding have been proposed in this area. One of them is massive gravel outtake in the outlet of the river, to increase the capacity of the river course and thereby lower the water level during floods. Gravel outtake in this part of the river is considered to have large negative consequences for the natural environment, both for birds, fish, other freshwater organisms and the forested floodplain along the river. It can change the ice situation during winter, and erosion and sedimentation both upstream and downstream the gravel outtake. It is also a measure which needs frequent and costly maintenance. Another measure which has been proposed is a flood barrier close to the river, on the riverbank. This is also considered to be harmful for the ecosystem, and lead to a large increase in water level during floods due to a narrower river course. By building a receded green flood barrier, these negative impacts will be avoided.

Enhancing the natural value of wetland: The wetland between the river Gausa and the agricultural land/the sports arena is mapped as the nature type "forested floodplain", with very high natural value. The area consists of Grey Alder (*Alnus incana*) - and Bird Cherry (*Prunus padus*) forest, with several red listed species of trees and vascular plants. The area is also an important nesting area for passerine birds. The existing flood preventing measures of the riverbank has caused less flooding of the area, less variation in terms of species and nature types, and a general reduction in natural value. By removing the old and existing measures and keep the green flood barrier away from this area, it will allow the area to be more flooded, and re-allocated to its former state. This could also lead to this area becoming a part of an adjacent nature reserve.

Society
Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for society:

More robust sporting arenas: The measure will lead to more use of the sporting arenas. The football season in Norway is very short due to the climate. By avoiding flood events you will extent the period in which these fields can be used. By making the sporting arenas more available and prolonging the season, it will have an impact on public health.

More robust society: By preventing large floods, it will have an impact on society. The citizens will feel more safe and secure, and thus increase quality of life.

Participatory process (PHUSICOS D2.1; Chapter 4.1.7)
Work on the Lågen plan has been underway since 2013 and has included participatory processes, for example public workshops and public hearings. The measure at Jorekstad is taken from this plan and has thus participatory processes have been applied here as well. We therefore believe that the stakeholder participation has been ensured. Furthermore, the innovate procurement process we suggest, will also serve as a participatory process by inviting subcontractors, NGOs, and other interested parties to a dialogue conference as outlined in Appendix 1.

We also plan to hold a town hall type of meeting at Jorekstad with Lillehammer municipality as co-host, as early as possible after the measure is approved. The invitation would go out broadly, and vital stakeholders would be the sports club and swimming hall, residents, and NGOs.

Local economy
Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the local economy:

Less negative economic impact for landowners: The Norwegian system for natural disasters compensation works on a gradient. This means that if you experience the same type of damage in the same place, you will not receive full compensation after the first time it occurred. By reducing the damages, you also avoid this type of economic loss for the land owner.

2.3 Pyrenees, Santa Elena, Spain

2.3.1 Site description

The chosen place, known as Santa Elena, is a terminal moraine at the bottom of the Gállego River Valley that is on the edge of the regional road A-136 PK 3 + 700. One of the moraine's parts directly pours its materials onto the A-136 road, causing risk situations for the users of said communication channel. The landslides that can occur have a heterometric size, from small stones to blocks of several tons.

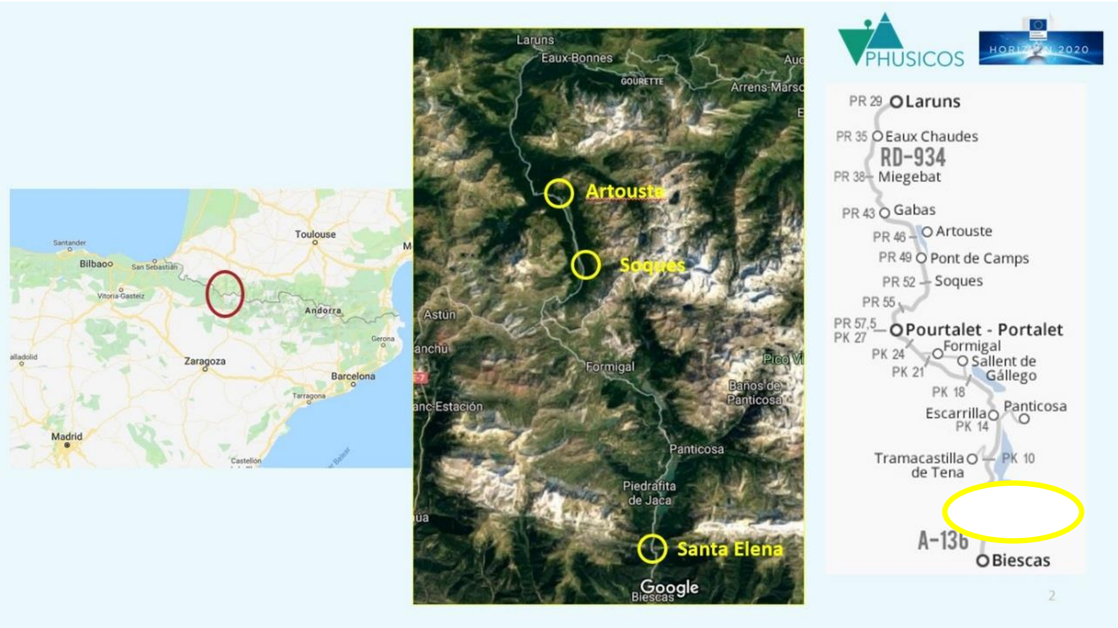


Figure 14. Pyrenees site location

The slope of the moraine that borders the A-136 has about 30 meters of unevenness, with an average slope higher than 80% being devoid of vegetation and with receding erosive processes and very significant vertical incisions, affecting about 150 m. of the road. Risk situations due to landslides can cause traffic accidents because it is a point of low visibility and change of gradient.

This road is an international pass (France-Spain) with a high traffic intensity - the average daily intensities are 3,000 vehicles per day and can reach values above 4,000 vehicles per day on weekends in the winter season due to the ski resorts of Formigal and Panticosa (first skiable domain of Spain in km of tracks) and summer.

In this place there are triple torsion protection meshes but they have lost much of their functionality, due to the vertical incisions and the strong receding erosion.

Figure 15. landslide phenomena along the road

The experience and knowledge of the road indicate a high risk at this point for the circulation with a high frequency (every year and with the highest values of the whole road A-136) of detachments of variable size on a road with a lot of circulation, as can be seen in the following graph.

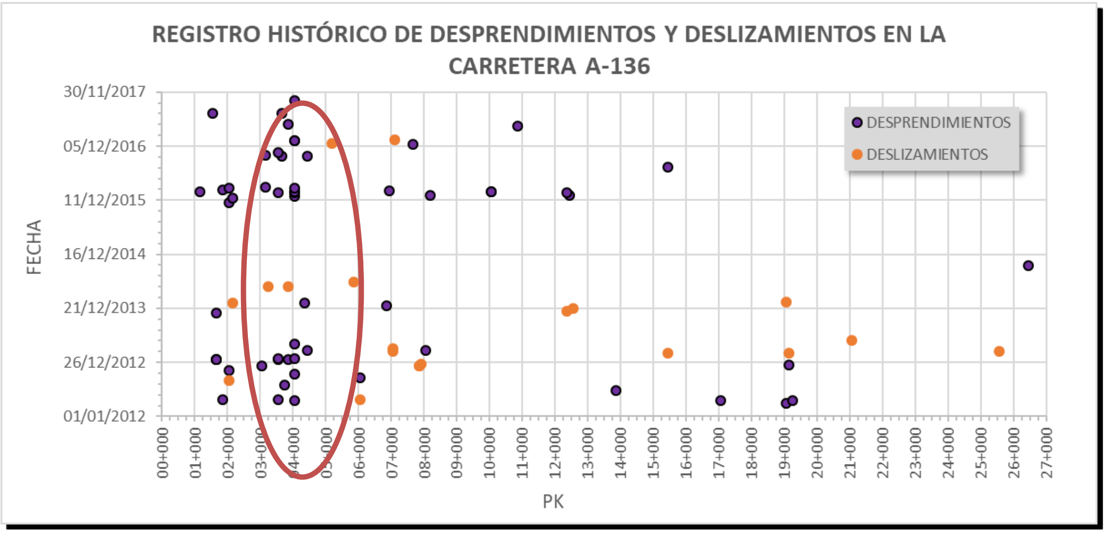


Figure 16. Historical landslide events along the road

A recent study on the natural risks that can affect the A-136 road (Study of natural risks that may affect the a-136 road (Lot 1. Spanish slope, carried out by Geoconsult Ingenieros Consultores, SA) that has been financed by the EGCT Portalet Space, gives this point a HIGH risk with one of the highest values of the entire A-136 road, as you can see in the following map. This high-risk classification is why this point is a priority and it is necessary to act to reduce the level of risk.

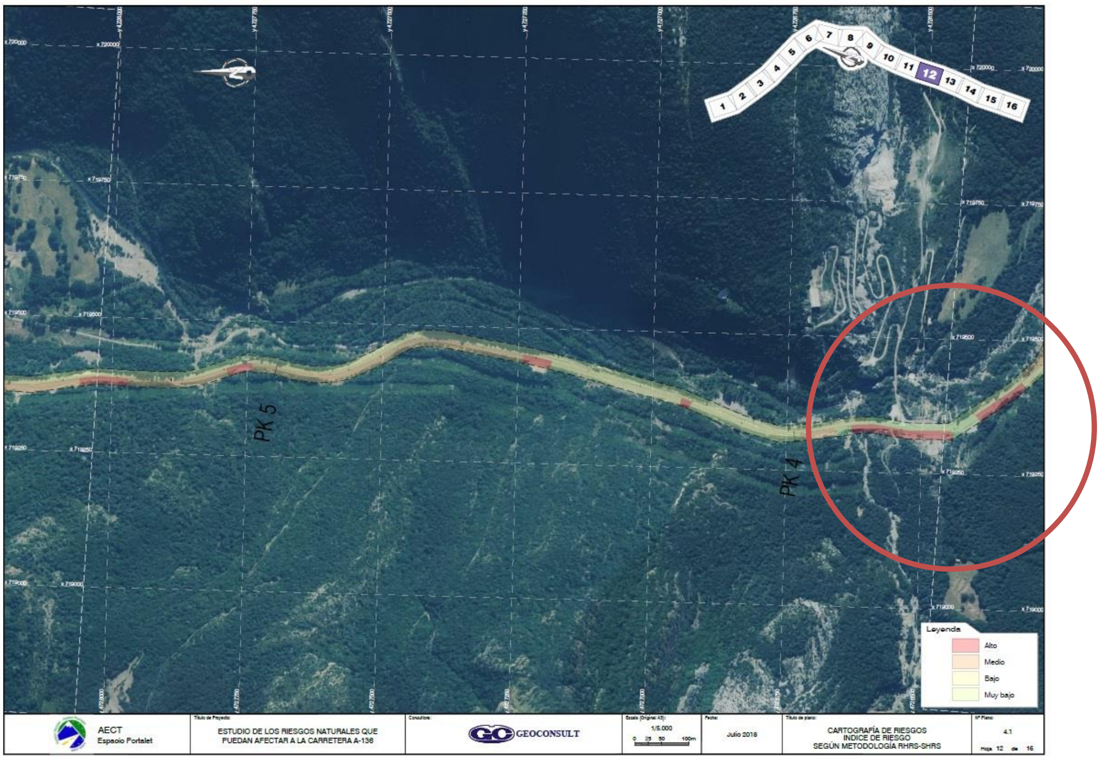


Figure 17. landslide hazard map along the road

2.3.2 Description of the Nature Based Solution

The techniques applied at this site are the creation of masonry terraces, improvement of drainage, soil improvement and implantation of autochthonous vegetation. The objectives are to decrease the slope and stabilize blocks and other unstable elements. Soil improvement will be done (incorporation of organic matter) and implantation of local vegetation to improve native biodiversity (*Salix sp.*, *Pinus sp.*, *Alnus sp*., and various shrubs).

These NBS will be implemented to create a staggered descent, mainly in areas of runoff accumulation imitating the mountain water courses (steep-pool type, search of the balance profile) complemented with arboreal and shrub revegetation to improve anchoring and drainage).

The aim is to recover solutions based on nature that are disused and / or little used by the Roads Services of both slopes, which has been shown to be more stable in the medium and long term and with a low maintenance cost.

In the Study phase, it is necessary to detail the diagnosis and prioritization of actions with the best NBS solutions based on the problem diagnosed and the previous selection of NBS performed.

Therefore, it is proposed to provide a solution based on nature that is realistic and compatible from a technical, economic and environmental point of view to replace the engineered solution in use. The current solution, anchoring by metal nets, has been stable in the short term but has lost efficiency and functionality due to the erosion over the moraine. The proposed solutions are based on finding a balance profile of the hillside by creating terraces either in masonry and / or in wooden gabions, improving drainage, improving the soil and implanting native vegetation on these terraces.

2.3.3 General assessment and needs by ambit

Risk reduction
PHUSICOS D2.1; Chapter 4.1.2

The implementation of the proposed solution would considerably reduce the level of natural risk analysed until an acceptable residual risk is reached. Also, the proposed solution is considered to have a realistic cost level and it is possible to carry out the the necessary protection works to reduce the risk.

From an ecological point of view, poor and undeveloped soil (morrhenic deposits) could be recovered in an improved soil where native vegetation could be implanted.

From a social point of view, giving an effective solution to a problematic area and with risk will allow to improve safety in the traffic through the A-136 in one of its black spots and of greater risk.

Technical & feasibility aspects
PHUSICOS D2.1; Chapter 4.1.3

Lower maintenance costs:
The proposed solution is proven under very similar conditions (Torrent of Arratiecho described above) and will be effective for this application. The solution given in the Torrent of Arratiecho can be considered very good after more than 115 years, allowing the reduction of erosion and trawling and the recovery of an autochthonous forest mass.

The effects in Santa Elena, once finished the works during the realization of the project, will be immediate with the practical reduction of detachments, getting a very smooth slope and the improvement of the soils that will allow the implantation of an autochthonous vegetation.

The maintenance plan should reflect at least the following most relevant aspects:

- Control of stability of structures.
- Control of the operation of drainages.
- Restoration of access roads to the works.
- Control and monitoring of soil improvement.
- Control and monitoring of vegetation implantation.

Environment & ecosystems
Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the environment:

The use of timbers, instead of grey infrastructures, constitutes a great benefit for the environment.

Society
Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for society:

As this project concerns a cross-border connection, it constitutes an important feature for the European Social Cohesion.

Participatory process (PHUSICOS D2.1; Chapter 4.1.7)
Leaders of the process: EGCT Space Portalet coordinated with Services of roads of the Government of Aragon and the Conseil départemental des Pyrénées-Atlantiques, as interested observer.

Actors of the territory: (environmental technicians of the GA, municipal managers (Biescas), environmental administration of the GA, conservationist associations, etc.).

Participation in all phases of information, consultation, design and completion of the work. The leaders of the process will lead the participatory process, mainly the EGCT. The participatory process will be carried out both with its own staff and with external personnel, and will be based on the following lines of work:

- Information.
- Communication and dissemination (Press releases, Social networks and project web, managed by WordPress).
- Realization of workshops with local actors.

Local economy
Co-benefits (PHUSICOS D2.1; Chapter 4.1.4) for the local economy:

This road is a key access to a sky resort and is also a cross border network and securing this road will have a positive impact on the local economy.

3 MONITORING NEEDS PER AMBIT

The monitoring needs are driven by the required indicators for the various criterion relevant for the NBS. In the Assessment Framework tool (Task 4.1), criterion and indicators are grouped and organised in the following objectives:

- Verify NBSs performances and their effectiveness with respect to risk reduction;
- Assess the technical and economic feasibility aspects;
- Assess the beneficial role of NBSs on the environment;
- Identify positive co-benefits and potentially undesirable side-effects from the societal point of view;
- Assess the effects of the NBSs on the local economy.

These are expressed as five Ambits:

- Risk Reduction
- Technical and Feasibility Aspects
- Environment
- Society
- Local Economy

Each Ambit is divided into more specific elements and sub-elements in a structured hierarchy, where the number of 'branches' at each level varies as needed (Figure 18).

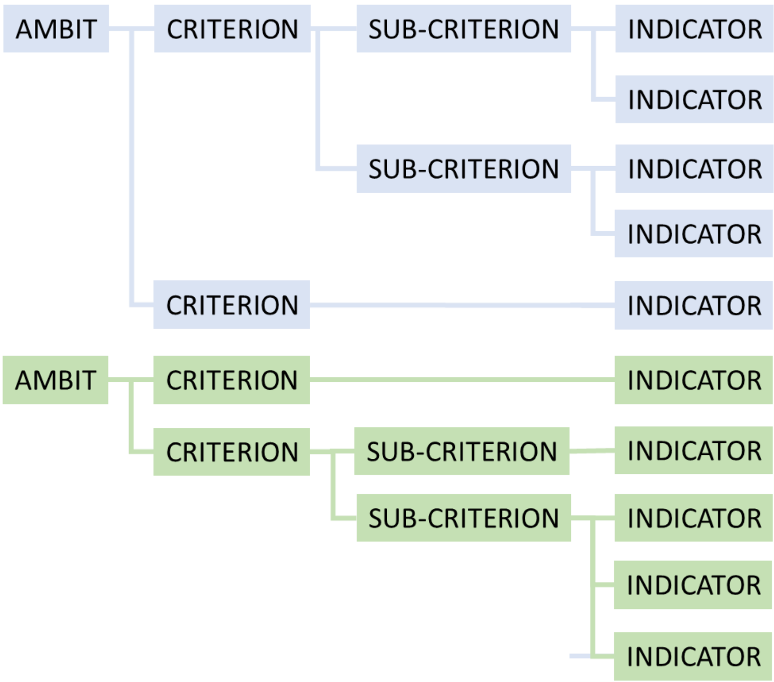


Figure 18. Structure of each ambit divided into elements and sub-elements

There are a very large number of Indicators and criteria given in the Assessment Framework tool. This is however a general set; for specific cases or applications it is necessary to select only the specific Ambits, Criterion and Indicators that are relevant.

In this document a smaller number of ambits and criterion are considered, see Table 2.

Table 2: List of considered criteria by ambit

Ambit	Criteria
Risk Reduction	Hazard
	Exposure
	Vulnerability
Technical & Feasibility Aspects	Technical Feasibility
	Economic Feasibility (affordability)
Environment	Water
	Soil
	Vegetation
	Landscape (Green Infrastructure)
	Biodiversity
Society	Quality of Life
	Community Involvement and Governance
	Landscape and Heritage
Local Economy	Revitalization of Marginal Areas
	Local Economy Reinforcement

The monitoring and measurement needs for each of these is described in the following sections. Relevant technologies or methodologies for performing the measurements are given in Section 4.

3.1 AMBIT: Risk Reduction

Within this AMBIT there are 3 main criteria with associated sub-criteria relevant for the case sites (Table 3):

Table 3: Risk reduction ambit: criterion, sub-criterion and monitoring and measurement needs

Criterion	Sub-criterion	Monitoring and measurement needs
Hazard	Erosion & rockfall risk resilience Flooding risk resilience	The selected indicators assess the site response to landslide, erosion and rockfall phenomena, as well as hydrological risks. The indicators are largely quantifiable through direct measurement approaches using instruments and systems combined with engineering analysis and modelling.
Exposure	Potential areas exposed to risks Potential population exposed to risks Potential species exposed to risks Potential buildings exposed to risks Potential infrastructure exposed to risks	The selected indicators provide information to assess the exposure to risk for specific groups or objects. This assessment is made by combining data and performing spatial analysis to produce maps indicating the spatial distribution of the group exposed to risk. Population data or engineering data may be obtained from public sources, engineering data may be produced through analysis or modelling.
Vulnerability	Potential population vulnerable to risks Potential Economic effects due to risks Potential infrastructure vulnerable to risks	Similar approach as for Exposure, although underlying data sets may vary. In this case data may focus more on demographics, statistical or financial data.

3.1.1 CRITERION: Hazard

Within this criterion there are two main hazards (Erosion & Rockfall, and flood) considered; for each indicator that quantifies the criterion, methods and sensors are proposed for it assessment (Table 4 and Table 5):

Table 4: Sub- criterion Erosion & Rockfall Risk Resilience: Methods and sensors for the indicators assessment

Assessment methods for the sub-criterion 'Erosion & Rockfall Risk Resilience'	*Relevant Indicators:*	Volume of eroded materials	Numbers of boulders	Volume of boulders	Arrival location	Boulders stability	Safety Factor (FS)	Occurred Landslide area /Risk Area (LA/RA)	Velocity of occurred landslide or rockfall (VL)
Airborne Laser Scanning		x						x	x
Differential SAR interferometry									x
Extensometers						x			x
Field survey			x	x		x			
Global Positioning System						x			x
Ground Based Radar for SAR interferometry									x
Modelling trajectography					x				
Numerical hydro-mechanical modelling							x		
Optic fibre									x
Probe inclinometers									x
Seismic acoustic monitoring			x		x				
Space-borne optical image								x	
Terrestrial laser scanner		x	x	x	x			x	x
Terrestrial Optical Photogrammetry		x	x	x	x			x	
Terrestrial Optical Photogrammetry / SfM									x
Time-Series Analysis of InSAR						x			x

Table 5: Sub- criterion Flooding Risk Resilience: Methods and sensors for the indicators assessment

Assessment methods for the sub-criterion 'Flooding Risk Resilience'	*Relevant Indicators*	Peak Flow	Peak volume	Flooded area
Hydrological simulations to reproduce hydrographs at varying the return period and the critical duration of the rainfall events from which the peak flow measurement can be derived		x	x	
2D simulations using hydrologic and hydraulic modelling		x		x
Direct measurements: water level gauges		x		
Direct measurements: velocimeters		x		
Spatial analysis coupled with hydraulic and hydrological simulations, able to estimate the depth, the elevation and the velocity of flood with using frequency, magnitude and shape of the hydrograph				x
2-D models are mainly based on solutions of the full or approximate forms of the surface water equations.				x

3.1.2 CRITERION: Exposure

For this criterion, the method for monitoring and/or assessing the indicator parameters is based on the combination of data and spatial analysis to produce maps indicating the spatial distribution of the group exposed to risk. The data sets required for this vary between the sub-criterion.

Table 6: Exposure Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment method
Potential Areas Exposed to Risks	Urban/residential areas ($A_{U/R}$):	Hydrological/hydraulic spatial analysis tools
	Productive areas (agriculture, grazing, industries) (A_{AGI})	
	Natural areas, site of community importance (sci), special protection areas (SPA):	
Potential Population Exposed to Risks	Inhabitants:	Statistical data for the various groups. exposed
	Commuters	
	Elderly, children, disabled	
Potential Species Exposed to Risk	Domestic and wild fauna	
Potential Buildings Exposed to Risks	Housing	Maps or plans and design details over the relevant structures and infrastructure
	Agricultural and industrial buildings:	
	Strategic buildings:	
Potential Infrastructures Exposed to Risks	Roads	
	Railways	
	Lifelines (watermain, sewerage, pipeline)	

3.1.3 CRITERION: Vulnerability

For this criterion we may use coupling of statistical data and spatial analysis of the area at risk. This spatial analysis will allow an assessment of the impact.

Table 7: Vulnerability Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment method
Potential Population Vulnerable to Risks	Population:	Statistical data for detecting the categories of people in the area. Assessment of vulnerability using a Vulnerability and Capacity Assessment (VCA)
Potential Economic Effects due to Risks	Economic value of the productive activities vulnerable to risks:	Statistical data for detecting the economic value of productive activities
Potential Infrastructures Vulnerable to Risks	Buildings:	Factual data over structures and infrastructure in an area. Application of Vulnerability Curve method, based on the detection of the correlation between the risk and the vulnerable buildings by empirical damage and fragility curves.
	Transportation infrastructures and lifelines	

3.2 AMBIT: Society

Within this ambit there are 3 main criteria with associated sub-criteria relevant for the case sites Table 8):

Table 8: Society ambit: criterion, sub-criterion and monitoring and measurement needs

Criterion	Sub-criterion	Monitoring and measurement needs
Quality of life	Leisure and connections increasing	This indicator addresses *recreational opportunity*, e.g. how much the Planning scenarios can increase the enjoyment of leisure activities in the area, making new areas available for recreational use and enhancing the accessibility of natural resources; and *sustainable mobility*, e.g. how much the planning scenarios can increase
	Social Justice	This indicator describes the beneficial effects ensured by the Planning scenarios in terms of social equity
	Ageing Contrast	A description of the beneficial effects ensured by the Planning scenarios on the demographic structure in the area, contributing to increase total population and decrease, at the same time, the elderly rate
Community involvement and governance	Participatory Processes and Partnership	This indicator is a measure of the quality of participation during NBS implementation process and the ability of local authorities to promote NBSs
Landscape & heritage	Identity	An indicator for the ability of NBSs to preserve traditional knowledge and to enhance the sense of belonging of local community
	Heritage Accessibility	A measure of how much NBS will improve the accessibility of natural and cultural heritage in the area which previously was not accessible
	Landscape perception	A measure of how much NBS will make landscape perceivable, through new scenic sites and paths, and contribute to create new landmarks in the area

Criteria and indicators within this ambit are quite complex, and all forms of monitoring technology and methods may apply depending on the specific indicator.

3.2.1 CRITERION: Quality of Life

For this criterion, the method for monitoring and/or assessing the indicator parameters is based on data acquisition from different types of sensors or means (Table 9):

Table 9: Quality of Life Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment methods								
		Roaming observers	Surveillance cameras	Surveys (interview)	Geo-tagged social media	Satellite imagery / GIS	Counting (turnstiles)	Thermal cameras	Mobile Phone CDR data	Public/private databases
Leisure and Connections Increasing	Number of visitors in new recreational areas	x	x	x				x	x	
	Sustainable transportation modes allowed	x	x	x	x					
	Different activities allowed in new recreational areas	x	x	x	x					
	Average distance of natural resources from urban centres/train stations/public transportation:			x		x				
	New pedestrian, cycling and horse paths			x		x				
	New links between urban centres and activities			x		x				
Social Justice	Easy access for people with disabilities	x		x						
	Rate of increase in properties incomes:									x
Ageing Contrast	Population increasing (natality+ immigration)									x
	Elderly rate									x

3.2.2 CRITERION: Community Involvement and Governance

For this criterion, the method for assessing the indicator parameters is based on data acquisition, which varies between the sub-criterion.

Table 10: Community Involvement and Governance Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicators	Assessment methods					
		Participant lists in events or meetings	Document distributions	Registered users of portals or web info	Social Media interactions	Public data-bases	Public plans
Participatory processes and partnership	Citizen involved:	x	x	x	x		
	Stakeholders involved	x	x				
	Public-private partnership activated					x	
	Policies set up to promote NBSs					x	Municipal land use plans; River Basin Authorities Plans

3.2.3 CRITERION: Landscape & Heritage

For this criterion, the method for monitoring and/or assessing the indicator parameters is based on data acquisition from different types of sensors or means (Table 11):

Table 11: Landscape & Heritage Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicators	Assessment methods:					
		Observation	Survey	Satellite imagery	LIDAR with spatial analysis	Social media	Public data-bases
Identity	Traditional knowledge and uses reclamation	x	x				
	Traditional events organised in new areas					x	x
	Social active associations					x	x
Heritage Accessibility	Natural and cultural sites made available	x	x	x		x	
Landscape Perception	Viewshed				x		
	Scenic sites and landmark created	x	x		x		
	Scenic paths created	x	x		x		

3.3 AMBIT: Local Economy

Within this ambit there are 3 main criteria with associated sub-criteria relevant for the case sites (Table 12):

Table 12: Local Economy ambit: criterion, sub-criterion and monitoring and measurement needs

Criterion	Sub-criterion	Monitoring and measurement needs
Revitalization of Marginal Areas	Promotion of Socio-Economical Development of Marginal Areas	the ability of NBS to promote socio-economic development in the area through the creation of jobs related to the creation and the maintenance of NBS itself
Local economy reinforcement	New areas for traditional resources	how much area NBS will be made available for traditional activities in rural mountain landscape (e.g. agriculture, livestock, fishing, etc.), previously not usable because dangerous or unreachable
	Enhancement of local socio-economic activities	the increase and enhancement of local socio-economic activities induced by NBSs, such as the productivity of rural areas

A general challenge for assessing these criteria is to define what is ‘nature-based’ as opposed to ‘environmental’ activities. Another challenge is to differentiate between activities or growth resulting from traditional building and construction versus that which arises from NBS building and construction.

3.3.1 CRITERION: Revitalization of Marginal Areas

For this criterion, the method for monitoring and/or assessing the indicator parameters is based on the data acquired by different means or methods (Table 13):

Table 13: Revitalization of Marginal Areas Criterion: indicators, monitoring and data for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment/monitoring approach	Data access and data collection methods
Promotion of socioeconomical development of marginal areas	Jobs created in the nature-based sector	Count of job creation and new recruitments to jobs promoting natural environment enjoyment activities	Public and private databases on job creation and economic activity. Surveys and interviews Literature reviews Economic models
	Jobs created in the nature-based solution construction and maintenance	Count of job creation and new recruitments to build the NBS infrastructure and for activities related to maintenance of it.	
	New employment in the tourism sector	Count of job creation in activities related to tourism sector in the study area;	
	New activities in the tourism sector:	Count of new companies or service offerings in recreation and tourism.	Public and private databases on tourism activities. Surveys and interviews
	Gross profit from nature-based tourism:	Study of annual economic data	Public and private databases on job creation and economic activity. Economic models
	Touristic activeness enhancing		Surveys and interviews. Roaming observers, counting of visitors. Public and private tourism databases

3.3.2 CRITERION: Local Economy Reinforcement

For this criterion, the method for monitoring and/or assessing the indicator parameters is based on the data acquired by different means or methods (Table 14):

Table 14: Local Economy Reinforcement Criterion: indicators monitoring and data for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment/monitoring approach	Data access and data collection methods
New areas for traditional resources	New areas made available for traditional activities	Assess changes in land use, e.g. introduction of agriculture, livestock, fishing or other uses not previously at area.	Public and private databases over land use. Satellite imagery and remote sensing
	Forest area planted	Assess change in forest coverage	Land use, land cover and land use change models
Enhancement of local socio-economic activities	Rural productivity index	Assess type of cultivation taking place and the mean profit per hectare of each cultivation	Direct observation and surveys Optical photogrammetry using aerial or satellite platforms

3.4 AMBIT: Technical & Feasibility Aspects

Within this AMBIT there is 1 main criterion with associated sub-criteria(Table 15):

Table 15: Technical & Feasibility Aspects ambit: criterion, sub-criterion and monitoring and measurement needs

Criterion	Sub-criterion	Monitoring and measurement needs
Technical feasibility (affordability)	Cost benefit analysis of the intervention	Various financial analyses to assess this
	Landscape Coherence and Sustainable Use of Materials and Approaches	Inspections and studies of projects or project plans as implemented.

3.4.1 CRITERION: Technical Feasibility (Affordability)

For this criterion we may use various forms of financial / economic analysis to assess the indicators.

Table 16: Technical Feasibility Criterion: indicators and methods for the indicators assessment for each sub-criterion

Sub-criterion	Indicator	Assessment approach
Cost-Benefit Analysis of the Intervention	Initial costs:	Application of preliminary metric assessment and calculation to estimate the design and production costs, as a function of the design scenario and the specific site life-costs and rules
	Maintenance costs	Application of statistical data and economic parametrization to estimate the maintenance costs, as a function of the design scenario and the specific site life-costs and rules
	Replacement costs:	Estimation of the replacement costs and their fluctuation, depending on the market value of the interventions, as a function of the Net Present Value (NPV)
	Payback period:	Estimation of the Payback Period as ratio between the initial investment and the net cash flow per year, deriving from the activities started and promoted with the design intervention
Landscape Coherence and Sustainable Use of Materials and Approaches	Material used coherence	Monitoring of the selection and application of native materials and techniques as a comparison with similar design and applications
	Techniques used coherence	

3.5 AMBIT: Environment & Ecosystems

The deliverable D4.2 is dedicated to the Monitoring of ecosystem service. For each indicator of this ambit, some recommendations for the monitoring program are proposed in this report, and the analysis method is also described. Please refer directly to this deliverable.

4 MONITORING: TECHNOLOGY AND METHODS

Once each indicator has been defined, it is proposed here to identify the available and adapted sensors or methodology for monitoring the indicators. For each indicator of the

3 sites, it is proposed a description of different sensors/technology or methodology that could be applied for monitoring the indicators.

4.1 Purpose for monitoring and assessing indicators

The purpose of the monitoring system is the evaluation of the NBS performance, as well as the co-benefits of it. A logical approach is to present this in three phases representing the evolution of the life of the NBS: Baseline monitoring (BL), long-term monitoring (LT), early warning (EW).

A baseline is the existing condition of the site prior to the implementation of the design scenario. It represents the status of the site prior to the intervention and the basis for the NBS performance evaluation. Indeed, the performance evaluation is performed in a relative way, with respect to the baseline scenario and thus this stage of measurement and monitoring is of fundamental importance into the performance assessment process.

The indicator parameters from the Assessment framework are the key data required and establishing the baseline means evaluating the Indicators of the case study matrix. The Assessment Framework tool is described in deliverable D4.1 and provides the approach used to evaluate NBS performance in the management of the risk process, and to assess the environmental and socio-economic co-benefit.

Monitoring over the evolution of the project is necessary for evaluating the performance and the co-benefits of NBS. This LT monitoring can be realised for different time temporal scales : Short-term (ST, within 5 years), medium-term (MT, 5-10 years) and long-term (LT, over 10 years), according to the definition from (Raymond et al., 2017a).

The PHUSICOS objective is to demonstrate the use of NBS to reduce the risks related to hydro-meteorological events in mountainous and rural contexts. This brings Early Warning of impending risk into context, and monitoring key indicators related to the risk disaster and hazard can provide data for this purpose. For this specific scope some new indicators can be added that are not properly related to the performance of the NBS but rather referred to the early warning system. These indicators are clearly related to each site and are a function of the specific hazard.

It is proposed in the next paragraphs a description of different sensors and technologies that could be applied for monitoring the indicators. The information described below are coming from several existing reviews on these technics: Chae et al., 2017; Hibert et al., 2017; Lissak et al., 2020; D4.1 from Safeland project.

4.2 Instruments and sensors (ground-based/in situ devices)

4.2.1 Seismic acoustic monitoring

Several landslide properties can be linked to features of the high-frequency seismic signals. Some studies have shown that the landslide volume is correlated to the amplitude (Norris, 1994; Dammeier et al., 2011) or to the radiated seismic energy of the high-frequency signals (Hibert et al., 2011; Yamada et al., 2012).

Moreover, the high-frequency seismic signals can also provide information on landslide dynamics. Indeed, a study provided by Levy et al. (2015) at the Soufrière Hills volcano on the island of Montserrat reveals that, the correlation can be found between the modelled force and the power of the short-period seismic signal for rockfalls that occurred. These authors also demonstrated a correlation between the maximum amplitude of the seismic signal (corrected from propagation effects), with the bulk momentum. These results imply new perspectives to quantify landslide dynamics directly from the seismic signals they generate, and then to develop future monitoring methods based on real-time detection and characterization.
Concerning the rockfall, some relationships exist between the potential energy lost, the kinetic energy and the seismic energy radiated by the impacts of rockfall. Therefore, it is possible to retrieve the mass and the velocity before impact of each block directly from the seismic signal.

4.2.2 Probe extensometers

Probe extensometers are used to measure the change in distance between two or more points within a drilled hole. The distance between the two points is determined by measurements of probe position. For obtaining absolute deformation, one measuring point must be at a location where no deformation occurs. If both points are in motion, then an external surveying method is needed to fix the position of one of the points. The pipe may be vertical, horizontal or inclined. Compared to fixed borehole extensometers, they allow for more measuring points and minimizing the cost of permanently installed instrumentations, but measurements are less precise.

4.2.3 Fixed borehole extensometers

Fixed borehole extensometers installed from ground surface may be used in soft ground or rock and may be Single Position for settlement measurements at one specific elevation or Multiple Position for measurements at several elevations.
They monitor the changing distance between two or more points along the axis of the borehole, without use of a movable probe. When the location of one measurement point is determined with respect to a fixed reference datum, the devices also provide absolute deformation data.

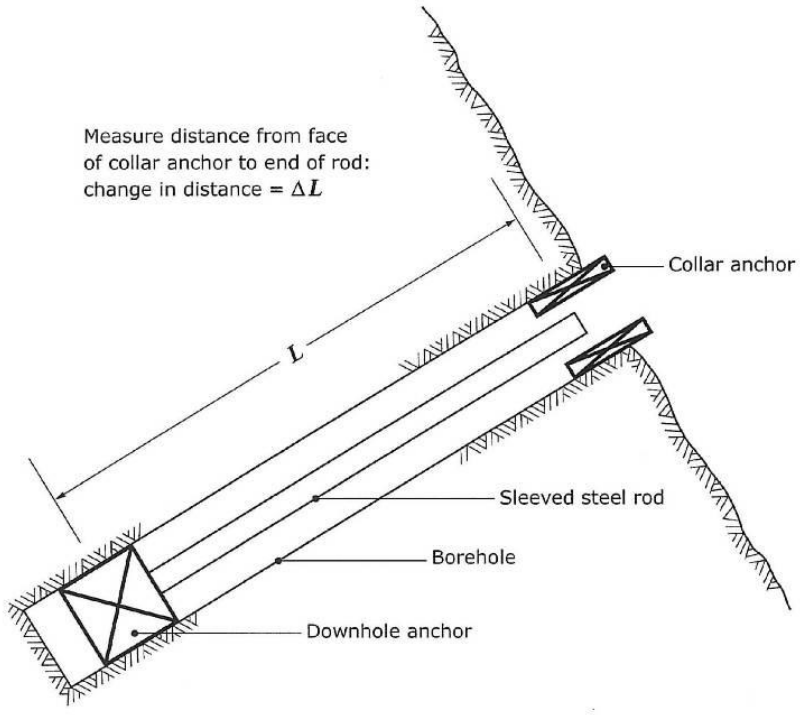


Figure 19. Fixed borehole extensometer (Dunnicliff et al., 2005)

4.2.4 Wire extensometers

The wire extensometer is a simple and low-cost device that allows the measurement of the relative displacement between two points, one in the landslide mass that is in motion and the other in stable ground (the borehole has been drilled vertically through the landslide body and crosses the surface of failure).

One advantage of the system application is in combination with inclinometric probe measurements in active landslides, extending the technical limitation of the probe inclinometer (typically a few centimetres of displacement along the slide surface could stop the probe lowered inside the pipe, requiring a new drilling activity).

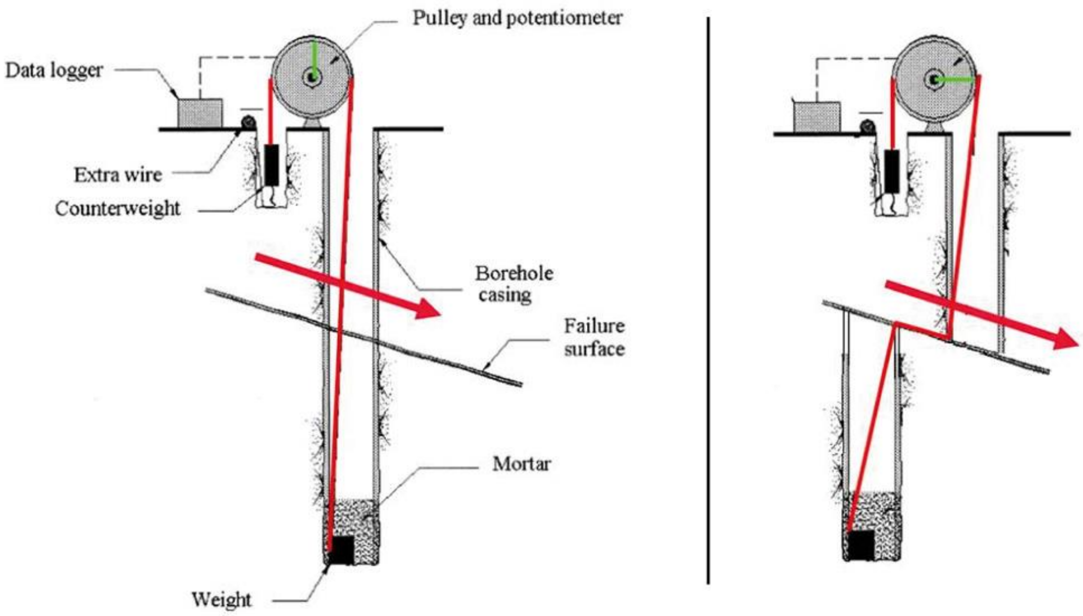


Figure 20. Scheme of the wire extensometer (modified from Corominas et al., 2000).

4.2.5 Probe inclinometers

Probe inclinometers are defined as devices for monitoring deformation normal to the axis of a pipe by means of a probe passing along the pipe. After the installation of the casing, the probe (containing a gravity sensing transducer designed to measure inclination with respect to the vertical) is lowered on a graduated cable to the bottom of the hole and winched upward, with stops at intervals for collection of inclination data. Inclinometer data measures the tilt of the probe and determines the shape of the inclinometer casing. Changes in shape could represent ground deformation or movement.

It permits the determination of the depth of a landslide movement; however, the probe inclinometers do not allow continuous recording of the displacements and cannot work if displacements are too important (a few centimetres).

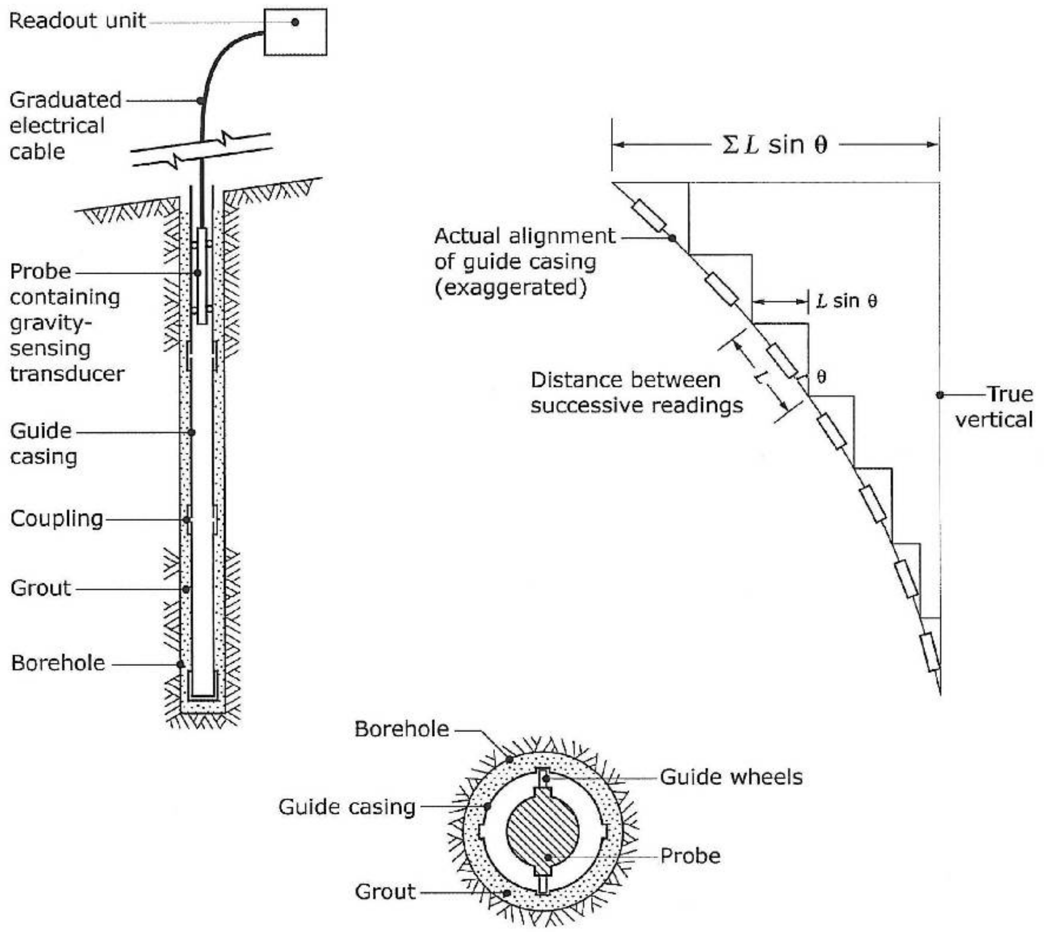


Figure 21. Inclinometer (Dunnicliff et al., 2005).

The probe measurement can be automated to perform repeated measurement over time. A control system operates an electric winch re-creating a measurement sequence. By automating data collection may be used to develop time histories of movement and allow estimating movement speeds.

4.2.6 Velocimeters

Several measurement principles are available, including laser doppler velocity, acoustic doppler velocity, and particle velocity.

Laser Doppler Velocimeter (LDV) measures local, instantaneous fluid velocities by detecting the frequency of light of small particles as they pass through a fringe or interference pattern. According to the Doppler principle, the frequency of the scattered light will be shifted by an amount directly proportional to the flow velocity. Mean and fluctuating velocity components can be determined online from the frequency record of the photodetector and the detected Doppler shifts. LDV techniques provide high resolution of local velocities within fluid volumes as small as 10^{-6} to 10^{-4} mm^3 (Doran, 2013). They have forward or backward configuration, i.e. the receiving optics are located opposite to the laser optics or on the same side as the laser optics. For a backward configuration, usually the receiving optics are integrated into the laser optics;

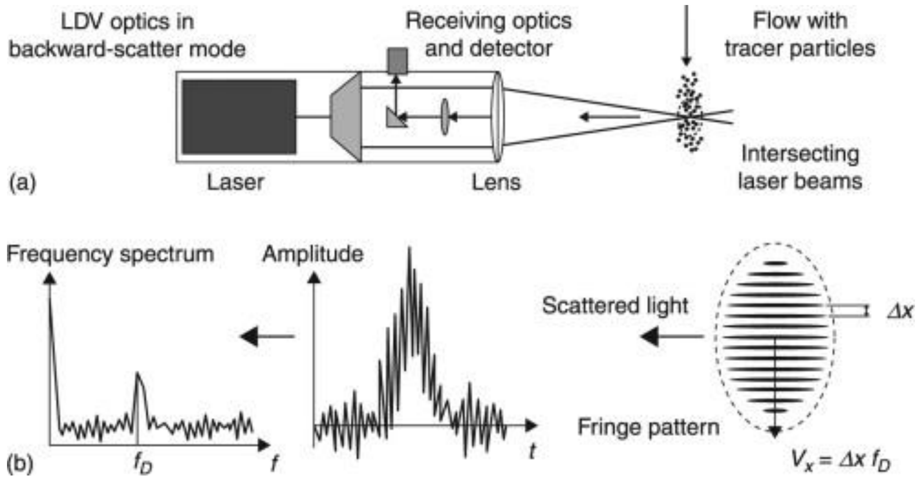


Figure 22. Typical LDV measurement set-up. (a) Experimental setup. (b) Analysis of results (Doran, 2013)

Acoustic Doppler Velocimeter (ADV) is a remote-sensing, three-dimensional velocity sensor, originally developed and tested for use in physical model facilities (Kraus et al. 1994). Its operation is based on the Doppler principle. It is implemented as a bistatic (focal point) acoustic Doppler system and is composed of a transmitter and three receivers. The instantaneous data registered with an ADV can be elaborated for assessing 3D mean velocity, the turbulent kinetic energy, the Reynolds stresses, and the power spectrum, among other statistical parameters. The main sources of error when analysing raw ADV velocity data are the Doppler noise and the aliasing of the signal. Both problems have been addressed in recent years by several ADV users (Cea et al, 2007).

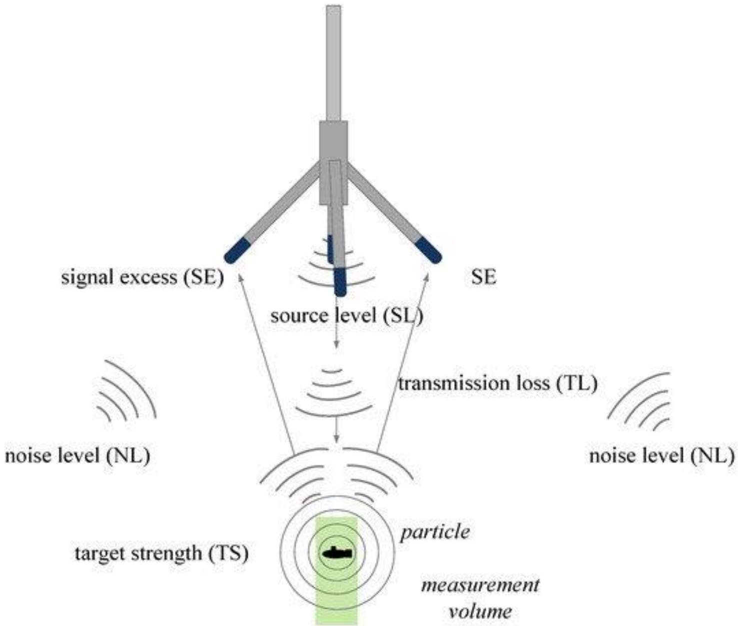


Figure 23. Acoustic Doppler Velocimeter functioning (Chmiel et al., 2019)

Particle Image Velocimetry (PIV.) is an optical measurement technique where the velocity field of a flow region within the flow is measured simultaneously. It allows quantitative flow field mapping technique, able to define the physical insight into the overall flow behaviour. PIV fosters both the elaboration of measurement data and the visualization of flow structures (Atkins, 2016).

4.2.7 Water Level Gauges and loggers

Water-level gauges with recorders (Limnographs) are devices for measuring water level by recorders. They include a limnograph connected with a pipe. The well water is kept at the watercourse level (river, stream, etc.) by means of a connection pipe. The pipe is laid lower than the minimum water elevation in the watercourse. The well bottom is placed deeper than the bottom surface of the connection pipe. The well is covered with a solid double cover plate, by locating the lower cover plate at 0.3-0.5 m above the soil surface to protect the well against freezing.

Capacitive Sensors are a type of sensor technology which has been proven to be stable, can provide high resolution and can be constructed using various materials, assuring low cost. Capacitive-type sensors can be of various shapes, to provide the ideal capacitor, which will be affected by the least undesirable parameters, such as the cable capacitance, variations due to temperature or parasitic capacitances created between the sensor and nearby objects (Loizou and Koutroulis, 2016);

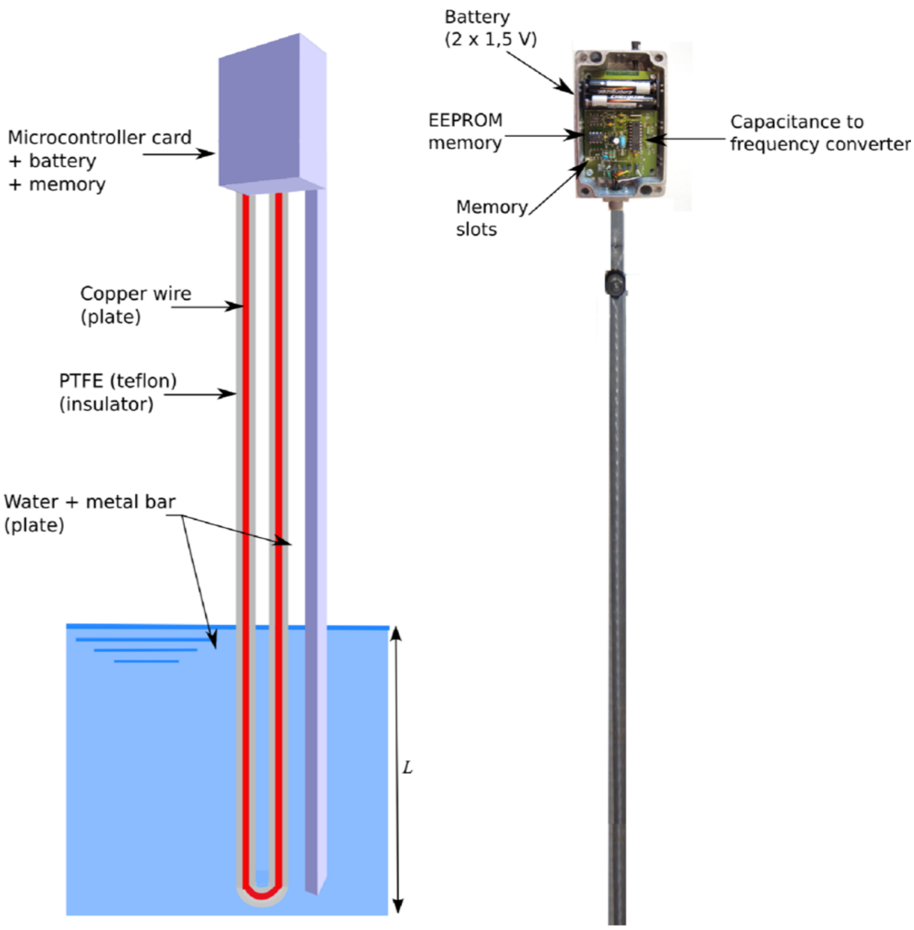


Figure 24. Capacitive sensor scheme (Chmiel et al. 2019)

A water level logger is a combination of a datalogger and submersible pressure transducer combination designed for remote monitoring and recording of water level or pressure data. Typically, these can record data locally or support data transmission to a server/cloud service. Most devices can support a variety of logging intervals and may include onboard data processing or calculations.

4.2.8 Optic fibre

Fibre optic sensors are based on the principle of changing the properties of light passing through (or reflecting from) the sensing point. Changes can include variations of intensity, polarization and spectral content of phase. Different kinds of sensing techniques exist, including change of light intensity, interferometry, fibre Bragg grating, adsorption measurement and distributed sensing. Fibre sensors are available for a wide range of physical parameters, such as pressure, temperature, strain etc. For more information, see Leung et al., 2015; Yong et al., 2020.

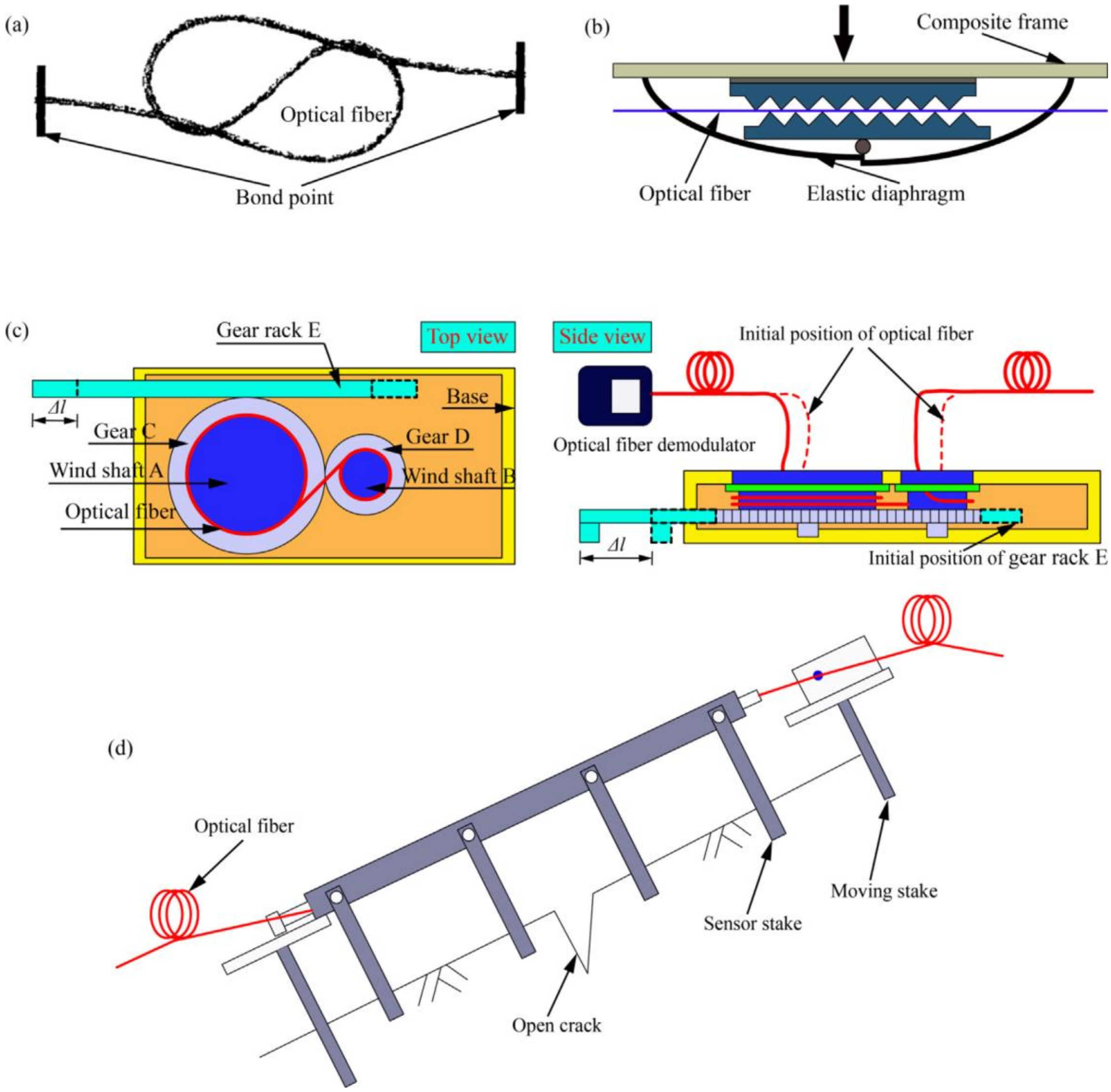


Figure 25. Schematic views of bend loss-based fibre optic sensors from Yong et al., 2020

4.3 Survey methods (observations and spatial data)

4.3.1 Direct and indirect observations

This approach refers to the idea of 'seeing' behaviours or effects through the eyes or actions of persons, either directly or through proxy measurements.

Observations may be made in different periods over the year, for instance one week for each season, so that the total number of observations made can be aggregated over a period by extrapolation.

Data may be specifically collected for the application, or it may be re-purposed or adapted from other uses. For example, consultation of data provided by official databases (e.g. National institute of statistics, Regional tourism agency, etc.) on tourist arrivals in the study area over a year may be re-purposed and combined with other data to evaluate the anthropogenic loading and its effects on a rural area.

Some possible techniques:

Roaming observers
Roaming observer (Muhar et al, 2002)

Counting

- Access digital counting through turnstiles at entrance point (if the area is fenced)
- Distribution of questionnaires, informational materials or other documents
- Number of users on web sites or information portals
- Number of likes or comments on social media platforms

Cameras
Surveillance cameras and time-laps video recording (Arnberger and Hinterberger 2003);
Thermal cameras (pyroelectric sensors) (Andersen et al., 2014).

Data tracking
Call Detail Record (CDR) data of mobile phones (Siyang Qin et al., 2019);
Geo-tagged social media data (Hausmann, 2017; Heikinheimo 2018).

Participant lists
Keeping track of numbers and/or details of persons participating in meetings, events or other activities requiring active participation.

Proxy data
Consultation of proxy data (e.g. amount of solid urban waste produced; electricity consumption in private houses; number of vacation houses available; tourist tax; etc.).

4.3.2 LIDAR: Terrestrial/Airborne laser scanner

The acronym LIDAR stands for LIght Detection and Ranging. When mounted over a ground-based platform, this instrument is also known as a Terrestrial Laser Scanner (TLS) or ground based LIDAR. When mounted on an aerial platform (drone, aircraft, satellite) it is known as an Airborne Laser Scanner (ALS) or aerial LIDAR.

The measurement principles are presented in Petrie and Toth (2008), Shan and Toth (2018) and Jaboyedoff et al. (2012). A LIDAR is a measuring instrument based on laser technology that can measure distance to a high degree of accuracy between the instrument and an object to be measured. It is based on a point cloud using distance measurement by the delay between the sending of an infrared laser pulse and the return of the reflected pulse. The laser instrument measures the precise time interval between the pulse emitted by the laser beam located at point A and its return after reflection from the object to be measured located at point B (Petrie and Toth 2008). It provides very high-resolution data with several million georeferenced 3D point clouds and high-resolution DEM reconstruction (centimetric/decimetric). Moreover, with multiple flights from different LOS in ALS or with different observation positions in TLS, it is possible to obtain a high resolution for shadow areas and even for hanging walls in rock slopes (Gigli and Casagli, 2011; Jaboyedoff et al., 2012; Gigli et al., 2013).

The main differences between TLS and ALS (also referred to as LiDAR) refer to the acquisition geometry and distance. In the case of ALS, the LOS is almost vertical and there is the need of fast acquisition rates during airplane routing that limit ground resolution. This is a limitation to measure steep slopes, hanging slopes and shadowed areas and to a point density in the range 0.1–100 pts/m^2. In the case of TLS, instead, both the distance of acquisition and the LOS are very flexible, and a near-vertical cliff geometry may easily be acquired. Point density is much higher, ranging from 50 to 10,000 pts/m^2. Consequently, the nominal accuracy is different and is about one order of magnitude higher in TLS than in ALS (Jaboyedoff et al., 2012).

The repetition of the same measurements at different times allows for the use of ALS and TLS systems in landslide monitoring. Several acquisitions of LIDAR data can be compared to detect 3D temporal variations of the measured area. Therefore, application of LIDAR for displacements measurement can be advantageous for very fast and very slow-moving landslides. These techniques provide high-resolution 3D points clouds and infra-centimetric resolution models.

In some cases, multitemporal point clouds from TLS can be combined with ALS to assess vertical/horizontal displacement fields at various scales, to maximize spatial coverage and point density.

Using this method, it is also possible to detect sudden changes in the morphology of the slope, allowing the characterization of the morphology, magnitude, frequency and location of the detachment area of the rockfalls occurred during the monitoring period. Similarly, this technique is able for the detection of rockfall precursory indicators such as minor rockfall events leading to grater failures (Rosser et al., 2007) and small-scale deformations (Abellán et al., 2009; Abellán et al., 2010).

But according to the study area, application of TLS can be spatially limited because of the field accessibility, vegetation cover and laser range (Niethammer et al. 2012). In this context, the characterization of the landslide kinematics is challenging, and the combination of tools is therefore required.

Compared to terrestrial photogrammetry, this instrument provides a high density point cloud (per m^2) measuring all elements of the landscape. Consequently, the reflected pulse can be processed to distinguish the vegetation from the soil to extract it. However, TLS is more expensive from a financial point of view than TOP. It also requires more operators on the field. Besides, the protocol to be implemented with TLS can be difficult, especially for irregular terrain and coastal areas.

The main limitations of LiDAR systems for monitoring, then, are: i) the lack of relative millimetre-accuracy capability when comparing different acquisitions at different times, which hampers slow displacement detection, unless permanent reflectors are installed in situ; ii) the lack of high-frequency acquisition, due to the complex pre- and post-processing needs and to the relevant volume of point clouds in terms of data storage, which hampers fast displacement monitoring; iii) the lack of a robust 24/7 operability, due to the low signal to noise ratio generated by atmospheric effects such as rain, fog, mist, clouds and dust.

The accuracy of DEMs and 3D models derived from ALS depends on several factors, such as the flight altitude, the quality of LiDAR used, the configuration of the topographic surface and the vegetation effects.

Due to its higher spatial resolution and to the ability of covering near-vertical cliff faces, the use of TLS is much more common than ALS for the study of rock masses affected by rock falls (Abellan et al., 2006, 2009, 2010; Gigli and Casagli, 2011; Gigli et al., 2013). Conversely, if the area to be scanned is almost flat or has a notable extension, TLS has a limited usability and ALS must be used.

4.3.3 Optical Photogrammetry

Photogrammetry is based on an improved principle of stereoscopy, i.e., the reproduction of a relief perception from two flat images in the same way as human vision. The objective is to model a real object or environment in 3D from a multitude of 2D images using algorithms. Using multiple photographs, algorithms will use common pixels of each picture to reconstruct the geometry of the object which must be modelled.

However, there are limits due to photographic protocol. For example, a uniform light is essential on each picture, and the camera configurations should not be changed during the photographic acquisition. Nowadays, it is also difficult to remove totally vegetation from 3D models. Hence, others 3D modelling tools such as LiDAR are used to counter these difficulties.

Optical photogrammetry is a relatively low-cost approach for high-resolution monitoring. Optical images may be collected from various platforms: Ground based cameras (terrestrial optical photogrammetry, TOP), aircraft-based cameras (aerial optical photogrammetry, AOP) or satellite-based images (satellite optical photogrammetry, SOP).

For landslide assessment, Terrestrial Optical Photogrammetry (TOP) constitutes a low-cost system for high-resolution monitoring. The accuracy of this technology can be centimetric. The principal advantages concern the speed of the 3D processing speed, and the possibility of quickly mobilizing the equipment on the field in case of large events (landslide, floods …).

Aerial photographs and orthoimages are available in the visible domain (RGB) as well as other optical bands. These are essential for landslide detection especially for a historical reconstruction of the slope deformation using aerial images time series.

Space-borne optical image analysis has been the first tool to overcome traditional air-borne photogrammetry, essentially for reasons of costs. Indeed, this method has the potential to become an actual monitoring technique when applied routinely at revisiting time compatible with the landslide development. There are at present several VHR satellites operating for Earth observation that can be suitable for rapid mapping and monitoring by using change and target detection algorithms.

However, despite the improvements of technologies (increase in acquisition frequency and in the number of available post-processing tools), optical data for landslide analysis is still more used for target/change detection technique, rather than an actual real real-time monitoring tool. A possible exception to that is offered by UAV-photogrammetry based on structure from motion.

TOP with SfM (Structure from Motion) technique has been increasingly used in recent years (Abellan et al. 2016; Kaab, 2000; Delacourt et al., 2004; Debella-Gilo et al., 2011; Travelletti et al., 2012; Westoby et al., 2012; Lucieer et al., 2014; Stumpf et al., 2015; James et al. 2019). These are also refered as Optical correlation methods and have been adopted by many authors to easily measure and model surface displacements induced by mass movements.

4.3.4 Radar

Radio Detection And Ranging (Radar) technologies have been developed since the beginning of the 20th century as a technique to remotely detect objects. Radio waves, or microwaves, are electromagnetic waves of wavelength from 1 mm to 1 m. Then radar methods have been used for accurate detection of movements and Earth surface imaging. Compared to the optical and near infrared sensors, the radio waves are much less influenced and attenuated by the atmospheric conditions. Thus, data can be acquired even during heavy rainfalls (even though some significant interactions are reported for X-Band systems) or strong fog; Microwaves, in fact, are able to penetrate fog, clouds, light rain and even dust in most of the cases. Moreover, as a radar is an active sensor (sending the initial signal), data can be acquired as well during the night than during the day.

Since then, many other applications have been found for mapping and measuring soil subsidence, landslides, structure deformation, river and coastal dynamics.

4.3.5 SAR interferometry

Synthetic-aperture radar (SAR) is a form of radar. SAR uses a moving radar antenna to create two-dimensional images.

The principle of differential synthetic aperture radar interferometry (DInSAR, Rudy et al., 2018) is the comparison in range (sensor-target distance) between couples of radar images acquired at different times over the same area. The phase shift, suitably filtered, is proportional to the ground displacement component parallel to the LOS of the satellite.

The main use of DInSAR is the detection of small deformations or movements at the surface, analysing the phase differences between two scenes acquired at different times. DInSAR is a combination of three main processing steps: The Synthetic Aperture Radar (SAR), the Interferometry (InSAR), and the Differential InSAR (DInSAR).

However, DInSAR is only usable for detecting movements of the ground that occurred between the two acquisitions and subject to the condition that the field of motion must be well autocorrelated in space and have a smooth gradient in time. Another limitation is that the maximum accuracy of DInSAR is at the centimetre-scale whilst most of deep-seated landslides move very slowly, at rates of a few millimetres per year. In this range, DInSAR cannot be used as a monitoring tool and it is necessary to resort to time-series analysis of InSAR (TSA-InSAR).

There are two main types of TSA-InSAR, according to whether they are based on the measurement of phase differences on stable point reflectors (PSI methods) or on distributed reflectors (DSI methods).

A common characteristic of all TSA-InSAR methods is that they exploit multiple interferograms to generate long time series of ground displacement that cannot be produced with single-interferogram DInSAR. PSI methods provide very accurate displacement measurements over specific sub-pixel objects that can be identified one by one on the ground. This is very helpful in urban areas and to study the development of ground deformation affecting man-made structures.

DSI methods deliver slightly less accurate measurements, with respect to PSI, and are usually related to multiple pixel clusters in areas with or without strong reflectors. For this reason, they offer a higher information density in non-urban areas and are less sensitive to temporal decorrelation.

Different PSI and DSI methods exists (for more details on the techniques and algorithms, see Chae et al., 2017, Osmanoglu et al., 2016).

Ground-Based Synthetic Aperture Radar

Ground-based SAR (Tarchi et al. 2003; Herrera et al., 2009; Barla et al. 2010; Monserrat et al. 2014) uses a Radar sensor for enabling Synthetic Aperture processing in a similar way as for spaceborne imagery (see below). Currently, two concepts are most used to control the motion of such a sensor:

1) linear SAR, consisting in installing the radar on a rail (typically 2–3 m long) allowing a translation motion (e.g., Tarchi et al. 2003).

2) the radar is on a tripod with a mechanism allowing a rotation motion of the tool (e.g., Werner et al. 2008).

The choice between both configurations depends on the context of the motion to be observed. For a given sensor's characteristics, the configurations are not equivalent in terms of range and swath—use of rail is generally better for longer ranges but has a reduced swath compared to the tripod—and ease of installation—installed on a tripod is generally a more portable device.

For slope instabilities monitoring, GBSAR is used in an interferometric configuration. The tool can be installed in front of the slope to be monitored and acquires data with a repeat cycle. With this tool it is possible to monitor slopes in a range between about 100 m and few kilometres with a resolution of the order of 0.1 m depending on the distance to the sensor. It therefore allows to monitor different types of landslides, in terms of size and kinematics.

With respect to spaceborne interferometric techniques, GBSAR is suitable to monitor slopes with previously known motion. If spaceborne interferometric techniques cover wider areas and give information on past motions, they cannot provide a high temporal resolution comparable with GBSAR.

Both techniques having different domains of application can therefore be used in a complementary way. In addition, due to their characteristics, GBSAR tools with adapted communications systems can be used in early warning systems.

Finally, offset tracking techniques on the amplitude measurements can be applied to GBSAR data as a complement to interferometric processing (Crosetto et al. 2014). This non-interferometric approach permits to estimate slope deformation and can be useful for monitoring very fast motions (several m day^{-1}) where GB-InSAR is not reliable.

4.3.6 GNSS - Global Navigation Satellite System

GNSS stands for Global Navigation Satellite System and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes e.g. the GPS, GLONASS, Galileo, Beidou and other regional systems. We are generally most familiar with the GPS system.

GPS is another common method used in slope monitoring (Abidin et al., 2007; Calcaterra et al., 2012; Othman et al., 2011). The GPS is a radio navigation, timing and positioning system with a wide set of applications: from air, sea and terrestrial navigation, to environmental studies, natural resources management, geographical information system (GIS) data capture, surveying and geodetic global measurements. By tracking the electromagnetic waves that the GPS satellites are sending continuously to the world, the system can obtain the antenna position (longitude, latitude, and height, or X, Y, Z coordinates) (Gili et al., 2000).

The satellites compose the spatial sector. When fully deployed, each GNSS constellation has a basic setup of 24 to 30 satellites, deployed in several orbital planes. Each satellite sends continuously electromagnetic sinusoidal waves to the Earth, in several carrier frequencies within the L band. The GNSS system calculates the user position using a set of measurements called the observables. They consist of data derived from the electromagnetic waves received from each satellite. Positioning can be in real time or with post-processing.

Measurements can be carried out during night or day, under varying weather conditions. With the recent developed rapid static positioning techniques, the time for the measurements at each station is reduced to a few minutes.

In the usual 'manual' GPS surveys for monitoring, the precision of the positions is highly dependent on both the equipment and, fundamental, the selected method. When using a relative GPS high precision method, we can reach cm to mm accuracy, depending on the total log time, the number of satellites under tracking, their geometry (the spatial distribution on the user's horizon...), and on the network configuration (number of receivers working together, redundancy of the net, fixed base points...).

The method usually produces highly accurate geodetic results. However, the antenna of this system must have a clear access to at least four common satellites. The satellite cannot be effectively employed in jungle areas because its signal can be blocked by trees (Othman et al., 2011).

4.3.7 Airborne platforms for data collection

Airborne systems are based on a range of platforms and sensors (Red–Green–Blue, multispectral sensors, radar, thermal…).

The most affordable and flexible platforms ones are balloons, blimps balloon and small Unmanned Aerial Vehicles (UAVs), most commonly in the form of consumer or industrial drones. UAVs are widely used for landslide studies (Rau et al. 2011, Niethammer et al. 2012). These are less expensive than manned aircraft (ultralight trikes, helicopters, planes), these techniques provide high-resolution measurements of landslides.

4.4 Public and private data /databases

Various data sources available from public authorities or municipalities. Data accessibility might be an issue, as these data may also contain sensitive information (personal data or data that can be indexed to individuals or small groups)

It is expected that most data will be available at the national level, therefore more accurate regional and local data might be unavailable for a specific NBS, unless monitored in the implementation phase

4.4.1 Job creation and economic activity

Possible public data sources and/or databases

- National Statistical Institute
- Chamber of Commerce
- Government agencies relevant to nature-based sectors
- Government agencies related to environmental protection or protected area management
- Local ministries relevant to nature-based sectors, e.g. tourism, environmental protection, protected area management
- NBS databases and case studies
- NBS databases and case studies

Possible private data sources

- Procurement companies involved in nature-based solution construction and maintenance, e.g. landscape architects, building companies, ecotourism service providers.
- Data from these will most likely only be available 'at the source', i.e. with the organisations themselves. This data may be more ephemeral than public data bases and may also be more difficult to access.

Approaches to collect data

- Consultation of data on new jobs provided by official databases and counting the number of recruitments in activities related to natural environment enjoyment activities (e.g. trail guides, bike rental and repair, education to nature, equipment rentals, service outlets, events and instructor led activities)
- Counting the number of people that have been recruited to build the new infrastructure
- Counting the number of recruitments in activities related to new infrastructure maintenance

Challenges:

- Defining what is 'nature-based' as opposed to 'environmental'
- Data accessibility might be an issue, as these data are more likely to be held by public bodies.
- Data differentiation. For example, jobs created for NBS construction / maintenance are not differentiated from other construction employments in data records
- It is expected that most data will be available at the national level, therefore more accurate regional and local data might be unavailable for a specific NBS, unless monitored in the implementation phase
- Differentiating economic activity: for example, finding data on activities rather than employment in tourism will be challenging - this might be too specific

4.4.2 Tourism

Possible data sources

- OECD data on tourism
  https://stats.oecd.org/Index.aspx?DataSetCode=TOURISM_ENTR_EMPL
- World travel and tourism council data gateway (data request form available online)
- UN World Tourism Organisation data: UNWTO systematically gathers tourism statistics from countries and territories around the world into a vast database that constitutes the most comprehensive statistical information available on the tourism sector.
  https://www.unwto.org/data
- Local and regional tourism ministries or public organisation

Challenges

- Differentiation in the data: Is nature-based tourism the same as ecotourism?
- It is expected that most data will be available at the national level, therefore more accurate regional and local data might be unavailable for a specific NBS, unless monitored in the implementation phase

4.4.3 Land use

Possible data sources:

- Hazard maps;
- Land use in the study area through direct survey or Remote sensing data processing (Achard et al., 2017)
- The FAO's database, which has records on land cover and land use
  http://www.fao.org/faostat/en/?#data/
- The World Bank databank, which includes data on agricultural area by country
  https://data.worldbank.org/indicator/AG.LND.AGRI.ZS
- OECD data on agricultural land cover by country
  https://data.oecd.org/agrland/agricultural-land.htm
- GLOBIOM: IIASA's Global Biosphere Management Model (GLOBIOM) is used to analyse the competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors.
  https://iiasa.github.io/GLOBIOM/
- Copernicus Land Monitoring Service - Corine Land Cover: The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990) to standardize data collection on land in Europe to support environmental policy development. Updates were produced in 2000, 2006, 2012 and 2018. Change layers were produced for 2000, 2006, 2012 and 2018.
  https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-corine

- The Global Forest Watch: Global Forest Watch (GFW) is an online platform that provides data and tools for monitoring forests. By harnessing cutting-edge technology, GFW allows anyone to access near real-time information about where and how forests are changing around the world. *https://www.globalforestwatch.org/*
- National forestry organisations, such as the ONF in France or Norwegian National forest inventory *https://www.onf.fr/onf/connaitre-lonf/+/35::open-data-pour-mieux-partager-les-donnees-forestieres.html*
- *https://www.ssb.no/en/lst*
- The World Bank databank, which includes data on forest area by country *https://data.worldbank.org/indicator/AG.LND.FRST.ZS*
- The FAO's database, which has records on forest areas *http://www.fao.org/faostat/en/?#data/*
- Municipalities and other public agencies reports and public notices.
- Municipal land use plans;
- River Basin Authorities Plans

Challenges:

- The difficulty in defining *new* areas (new compared to what baseline?)
- The difficulty in finding time-series data. Most data will provide a snapshot in time, yet not provide the bigger picture over the past decades, which is what is needed to quantify new areas for traditional activities.
- Data inconsistencies through different local/national definitions of land cover categories (e.g. forests are defined differently in different countries or regions)
- Weaknesses of remote sensing data (often, in situ verification of data is needed)
- Most data sources are at the global or national level; regional and local data which are more accurate are harder to collect and collate
- Data are often not collected over time; hence it is difficult to deduce when forests were planted

4.4.4 Society and quality of life

Possible data sources

- National real estate monitoring agencies reports;
- National Statistical Institute
- Municipal General Register Office Reports
- Private data from real estate organisations

4.4.5 Social media

Tourist information web sites, social media pages, and local development websites

5 LIVING LABS

5.1 Application of the Living Labs Methodology

Monitoring and early warning system will be tailored to different needs, lifestyles and economic resources of users. The specific needs of the stakeholders must be considered when planning a monitoring. For example, in planning an early warning system it is necessary to consider the needs of population, concerning both the protection of people (considering different conditions of age, disabilities, awareness) and the safeguard of cultural and economic resources (safeguarding flocks and herds, loss of crops and other livelihoods).

The Living Labs (LL) methodology is an approach involving stakeholders in planning and decision processes. The use of LL will be tested in this context to define monitoring and measurement needs and provide the basis for detailed planning of monitoring systems for the demonstration cases. This portion of Task 4.3 will investigate how stakeholders and experts may work together in a living labs approach to refine design concepts and general recommendations into detailed monitoring system designs in preparation for procurement and implementation.

The following topics should be considered for the LL:

- Measurements or data needed
  - The choice of indicators to be taken under observation
  - The type of sensors/methodology used for monitoring them
- The use of data by stakeholders
  - The process and/or model applied to the acquired data
  - The resulting indicator obtained
  - The use of this indicator, for the decision making, as well as the way it can be communicated
- If early warning is the monitoring strategy:
  - The definition of thresholds
  - The decision processes in case of emergencies

5.2 COVID19 adaptations of the LL methodology

Typically, an LL should be arranged as an event or an interaction among stakeholders. However, due to the complications of the ongoing pandemic and restrictions on travel and congregation, a modified approach based primarily on online surveys has been developed.

A tailored online questionnaire has been created for each site. For that the software from Soscisurvey has been used (this society is a spinoff from LMU University in Munich, www.soscisurvey.de/). This software permits to design a questionnaire in all PHUSICOS languages.

The online questionnaire begins by informing the user of the objectives for the online interview (Figure 26).

Project Description

This survey is distributed in the context of the PHUSICOS project. The EU-project PHUSICOS (2018-2022) aims at fostering proof of the effectiveness of nature-based solutions (NBS) as an approach to reduce the risk of extreme weather events in rural European mountain areas. The name PHUSICOS originates from the Greek term *φυσικός* and can be translated with “according to nature”. The Innovation Action project is funded by the European Union’s Horizon 2020 research and innovation program.

The project aims at providing assessment of NBS impact. To do so, qualitative assessment is proposed for literature NBS stored in the platform and detailed assessment associated with monitoring network is implemented for each PHUSICOS demonstrator site.

The identification of NBSs indicators has already been performed and the objective of this interview is to have your point of view on the choice of the indicators, the way they can be monitored, and the way they can be used and communicated.

More precisely, the objective is to analyse:
- The choice of the indicators to be monitored,
- The type of sensors/methodology used for this purpose,
- The process and/or model applied to the acquired data,
- The resulting indicator obtained,
- The use of this indicator, for the decision making, as well as the way it can be communicated.

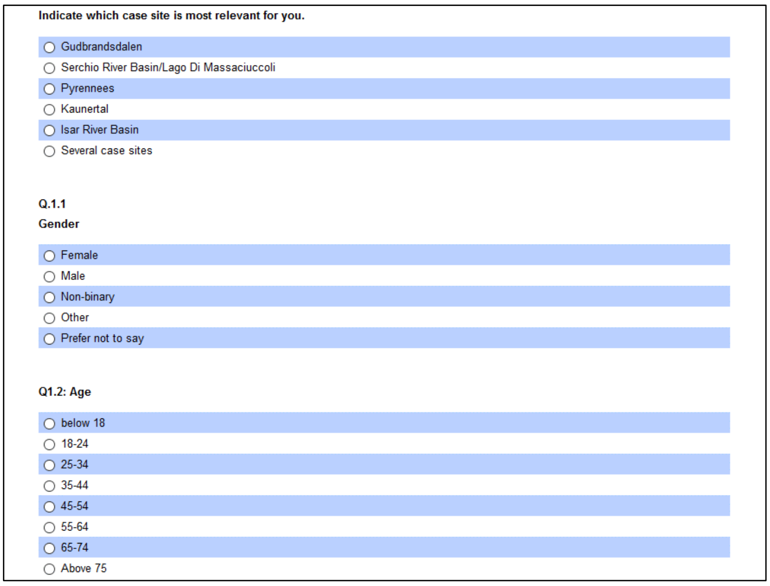
Figure 26 Introduction to online survey defining the objectives of the LL exercise

Each survey includes a common set of initial questions to establish demographic data (age, gender, type of organisation etc), followed by questions addressing relevant indicators, measurement technologies and techniques and other site-specific information.

To reduce the effect of 'survey fatigue', the total number of questions posed to a Stakeholder is limited based on the Stakeholder's personal priorities. This is done asking the Stakeholder to rank the ambits in order of priority, from 1 (unimportant) to 5 (very important), e.g. a Likert Ranking task. Based on this response, the Stakeholders 2 most important ambits (rated 4 and 5) form the basis for additional questions and answers.

5.3 Questionnaire: Serchio River Basin, Italy

This case study site will employ the use of buffer strips. The figures below present an extraction of the principal questions, specifically for this site, related to the design of the monitoring, and the way the indicators can be used and communicated.



Indicate which case site is most relevant for you.

- ○ Gudbrandsdalen
- ○ Serchio River Basin/Lago Di Massaciuccoli
- ○ Pyrennees
- ○ Kaunertal
- ○ Isar River Basin
- ○ Several case sites

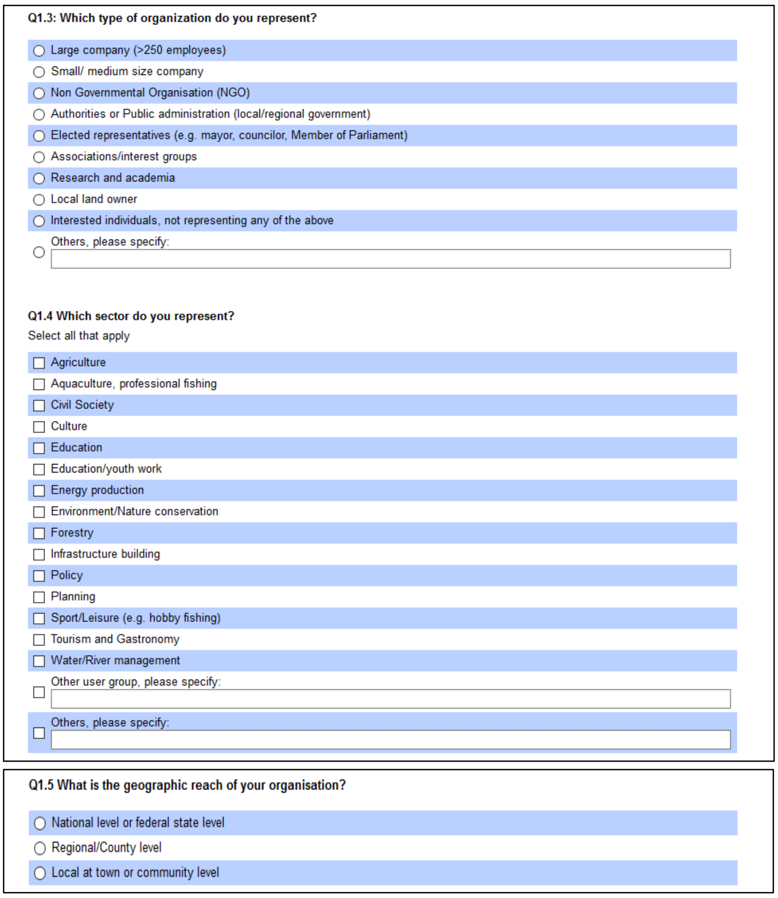
Q.1.1
Gender

- ○ Female
- ○ Male
- ○ Non-binary
- ○ Other
- ○ Prefer not to say

Q1.2: Age

- ○ below 18
- ○ 18-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ Above 75

Figure 27. Initial demographic questions



Q1.3: Which type of organization do you represent?

- ○ Large company (>250 employees)
- ○ Small/ medium size company
- ○ Non Governmental Organisation (NGO)
- ○ Authorities or Public administration (local/regional government)
- ○ Elected representatives (e.g. mayor, councilor, Member of Parliament)
- ○ Associations/interest groups
- ○ Research and academia
- ○ Local land owner
- ○ Interested individuals, not representing any of the above
- ○ Others, please specify:

Q1.4 Which sector do you represent?
Select all that apply

- ☐ Agriculture
- ☐ Aquaculture, professional fishing
- ☐ Civil Society
- ☐ Culture
- ☐ Education
- ☐ Education/youth work
- ☐ Energy production
- ☐ Environment/Nature conservation
- ☐ Forestry
- ☐ Infrastructure building
- ☐ Policy
- ☐ Planning
- ☐ Sport/Leisure (e.g. hobby fishing)
- ☐ Tourism and Gastronomy
- ☐ Water/River management
- ☐ Other user group, please specify:
- ☐ Others, please specify:

Q1.5 What is the geographic reach of your organisation?

- ○ National level or federal state level
- ○ Regional/County level
- ○ Local at town or community level

Figure 28. Demographics related to organisation and sector

Q.2.3 The following table lists a variety of possible indicators. How useful will these be for assessing NBS and making decisions?

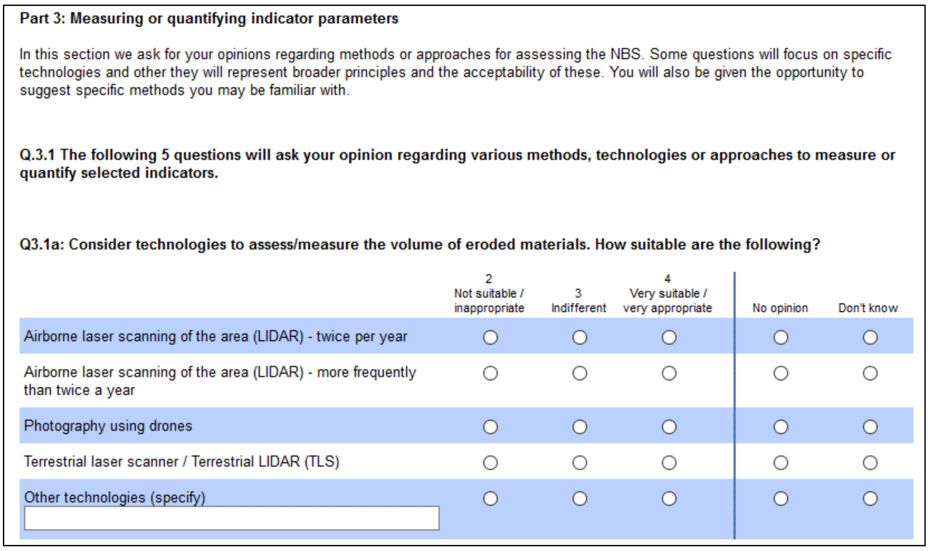
	1 Not important at all	2 Not important	3 Somewhat important	4 Important	5 Very important	No opinion	Can't judge
Volume of eroded materials							
Length of roads potentially exposed to risk							
Population potentially exposed to risk							
Initial costs of a solution to reduce risks							
Maintenance costs of a solution to reduce risks							
Composition of material used for implementation of the solution							
Physical parameters to analyze water quality							
Total Predicted Soil Loss (RUSLE)							
Total Vegetation Cover							
Abundance Of Ecotones/Shannon Diversity							
Sites with status of Community Importance (SCI) And Special Protection Areas (SPA)							
Visitor numbers in the area where a solution is implemented							
Citizen involved							
Policies set up to promote NBS							
Natural and cultural sites made available							
Jobs created in construction and maintenance of a solution							
Touristic attractiveness enhanced							
Rural Productivity Index (RPI)							

Figure 29. Evaluation of indicators

Q.2.4 Consider elements from the same set of indicators as in the previous questions: Should these measurements (assessments) be shared as public information to promote the NBS?

	Yes	No	No opinion	Can't judge
Volume of eroded materials				
Length of roads potentially exposed to risk				
Population potentially exposed to risk				
Initial costs of a solution to reduce risks				
Maintenance costs of a solution to reduce risks				
Composition of material used for implementation of the solution				
Physical parameters to analyze water quality				
Total Predicted Soil Loss (RUSLE)				
Total Vegetation Cover				
Sites with status of Community Importance (SCI) And Special Protection Areas (SPA)				
Visitor numbers in the area where a solution is implemented				
Citizen involved				
Policies set up to promote NBS				
Natural and cultural sites made available				
Jobs created in construction and maintenance of a solution				
Touristic attractiveness enhanced				

Figure 30. Assessment of use and confidentiality of indicator data



Part 3: Measuring or quantifying indicator parameters

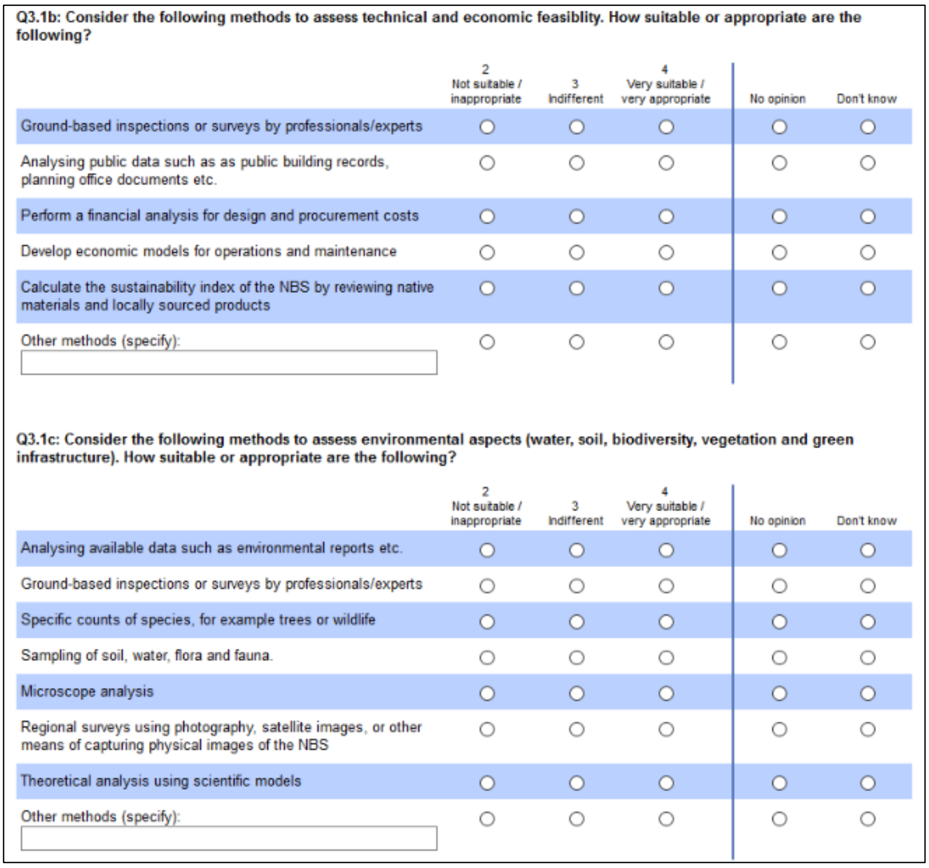
In this section we ask for your opinions regarding methods or approaches for assessing the NBS. Some questions will focus on specific technologies and other they will represent broader principles and the acceptability of these. You will also be given the opportunity to suggest specific methods you may be familiar with.

Q.3.1 The following 5 questions will ask your opinion regarding various methods, technologies or approaches to measure or quantify selected indicators.

Q3.1a: Consider technologies to assess/measure the volume of eroded materials. How suitable are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Airborne laser scanning of the area (LIDAR) - twice per year	○	○	○	○	○
Airborne laser scanning of the area (LIDAR) - more frequently than twice a year	○	○	○	○	○
Photography using drones	○	○	○	○	○
Terrestrial laser scanner / Terrestrial LIDAR (TLS)	○	○	○	○	○
Other technologies (specify)	○	○	○	○	○

Figure 31. Assessing measurement technologies



Q3.1b: Consider the following methods to assess technical and economic feasiblity. How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Ground-based inspections or surveys by professionals/experts	○	○	○	○	○
Analysing public data such as as public building records, planning office documents etc.	○	○	○	○	○
Perform a financial analysis for design and procurement costs	○	○	○	○	○
Develop economic models for operations and maintenance	○	○	○	○	○
Calculate the sustainability index of the NBS by reviewing native materials and locally sourced products	○	○	○	○	○
Other methods (specify):	○	○	○	○	○

Q3.1c: Consider the following methods to assess environmental aspects (water, soil, biodiversity, vegetation and green infrastructure). How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Analysing available data such as environmental reports etc.	○	○	○	○	○
Ground-based inspections or surveys by professionals/experts	○	○	○	○	○
Specific counts of species, for example trees or wildlife	○	○	○	○	○
Sampling of soil, water, flora and fauna.	○	○	○	○	○
Microscope analysis	○	○	○	○	○
Regional surveys using photography, satellite images, or other means of capturing physical images of the NBS	○	○	○	○	○
Theoretical analysis using scientific models	○	○	○	○	○
Other methods (specify):	○	○	○	○	○

Figure 32. Assessing the relative importance of methods for various assessment criteria (1/3)

Q3.1d: Consider the following methods to assess the involvement of citizens. How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Counting number of participants at events such as information meetings or other gatherings.	○	○	○	○	○
Maintaining lists of names of participants in public events	○	○	○	○	○
Counting participation levels in surveys/questionnaires.	○	○	○	○	○
Membership numbers in groups on social media	○	○	○	○	○
Collecting names through abonnements or memberships in groups	○	○	○	○	○
Counting 'likes' or reactions in social media; postings of images, numbers of views/shares.	○	○	○	○	○
Other methods (specify):	○	○	○	○	○

Q3.1e: Consider the following methods to assess policies and to promote the NBS. How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Review public documents prepared by municipalities and other public agencies reports on these specific topics	○	○	○	○	○
Consultation of municipal land use plans	○	○	○	○	○
Consultation of river basin authorities plans	○	○	○	○	○
Other methods (specify)	○	○	○	○	○

Figure 33. Assessing the relative importance of methods for various assessment criteria (2/3)

Q3.1f: Consider the following methds to assess the creation of jobs. How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Examine census data	○	○	○	○	○
Develop economic models	○	○	○	○	○
Perform literature reviews	○	○	○	○	○
Statistical analysis of jobs creation in sectors or areas affected by NBS (based on official databases)	○	○	○	○	○
Other methods (specify):	○	○	○	○	○

Q3.1g: Consider the following methods to assess improvements to tourism. How suitable or appropriate are the following?

	2 Not suitable / inappropriate	3 Indifferent	4 Very suitable / very appropriate	No opinion	Don't know
Collecting and analysing mobile phone data (position and/or usage)	○	○	○	○	○
Consultation of data provided by official databases (e.g. arrivals/overnight stays in the study area over a year)	○	○	○	○	○
Counting 'likes' or reactions in social media; tracking numbers of views/shares.	○	○	○	○	○
Direct surveys of persons in the area	○	○	○	○	○
Geolocation of posts on social media	○	○	○	○	○
Indirect data (e.g. amount of solid waste produced; electricity consumption in private houses; number of houses available for vacation; tourist tax; etc.)	○	○	○	○	○
Roaming observers interacting with persons at the location	○	○	○	○	○
Surveillance cameras and time-lapse video recording	○	○	○	○	○
Visitor counting at trails with sensors	○	○	○	○	○
Other methods (specify):	○	○	○	○	○

Figure 34. Assessing the relative importance of methods for various assessment criteria (3/3)

5.4 Results: Serchio River Basin

The questionnaire has been filled by 11 persons. The answers have been analysed and interpreted. The results are described below.

5.4.1 Demographic data

<u>Gender and age</u>
Responders are primarily male, with the majority in the ages of 45-54 years.

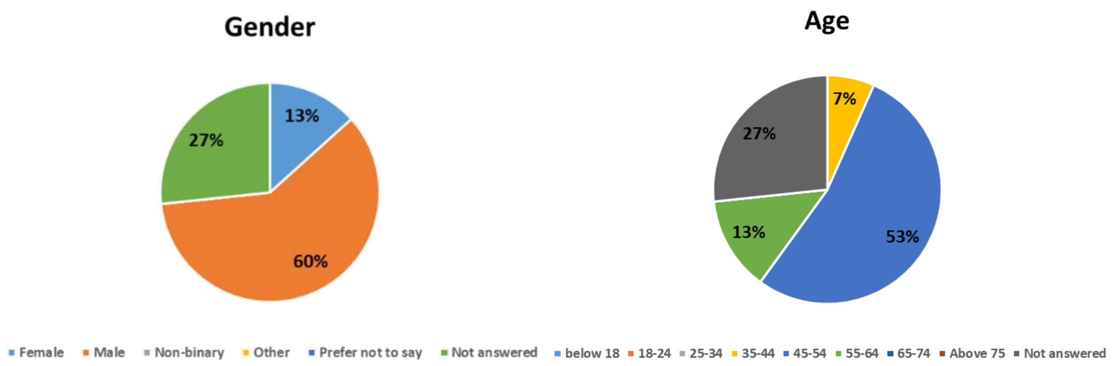


Figure 35. Gender and age of interviewees

<u>Type of organisation and geographic reach</u>

The following diagram indicates the typology of organization that interviewees represent. The most represented organization are research/academia (27%), followed by Authorities or Public administration (local/regional government) and Local land owner (13% for both). 33% of the interviewees doesn't provide any answer.

Most of the interviewees 'organization has a national level (34%), followed by local level (20%) and regional level (13%).

Figure 36. Represented organizations

<u>Sectors</u>

Sectors of activity represented by the interviewees indicate that agriculture, education, and environment are the most represented sectors. Note that multiple answers could be given.

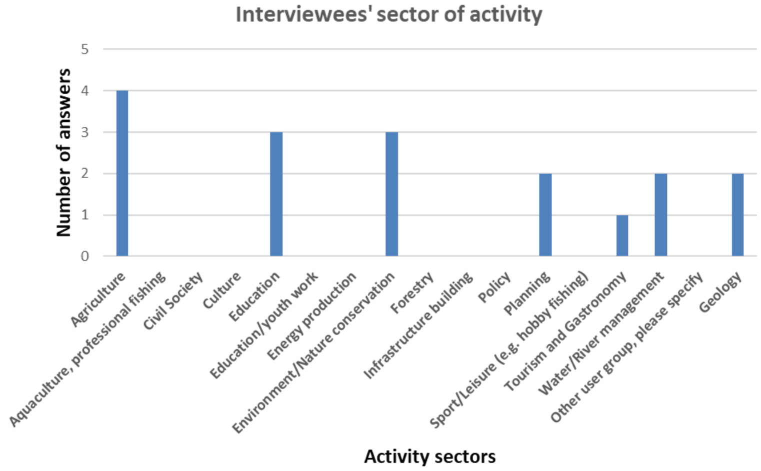


Figure 37. Sectors of activity represented

5.4.2 Indicator usability assessment

The following diagrams indicate the usefulness of indicators for assessing NBS for Risk reduction ambit, according to the interviewees responding to this question (27% of the reviewees doesn't answer to this question.

The results indicate that both the volume of eroded material, and the quantification of population potentially exposed to risk, are considered very important/ important (by 46% and 64% of the reviewees, respectively). At the contrary, the length of road potentially exposed to risk are less important (37% of the reviewees considers this indicator somewhat important, 9% considers it not important).

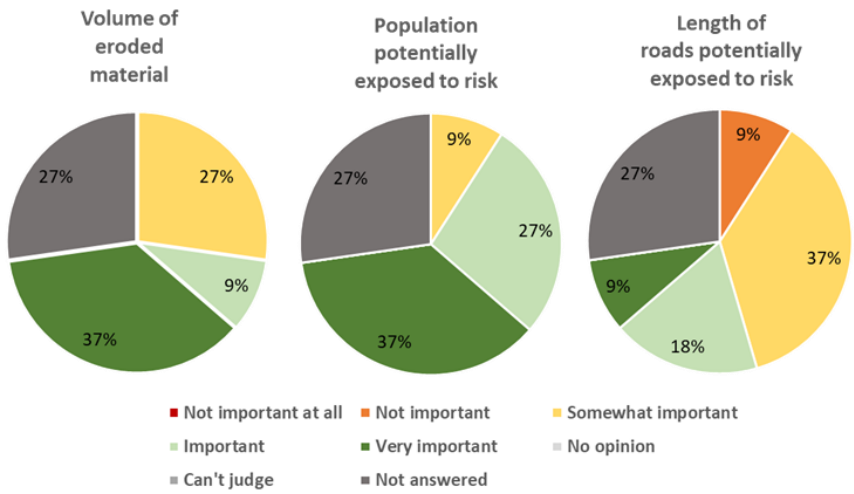


Figure 38. Usefulness of indicators for assessing NBS - Risk reduction ambit

5.4.3 Priority indicators by ambit

<u>Indicators for the Technical & feasibility ambit</u>

The initial cost of NBS, as well as the maintenance costs, are considered very important/important (by 73% of the reviewees for both). At the contrary, the composition of material used for NBS is less important (only 46% of them considers it important).

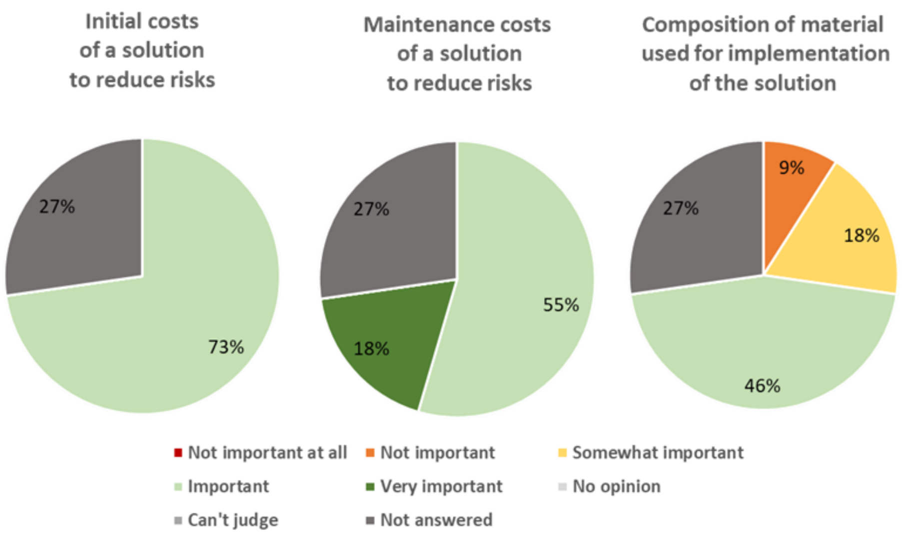


Figure 39. Usefulness of indicators for assessing NBS - Technical & feasibility aspects ambit

<u>Indicators for the Environment & Ecosystems ambit</u>

The physical parameters 'total predicted soil loss' and 'total vegetation cover' are considered very important/important with the same percentage (by 55% of the reviewees).

18% of interviewees could not judge the importance of the indicators 'Abundance of ecotones Shannon diversity' and sites with special status.

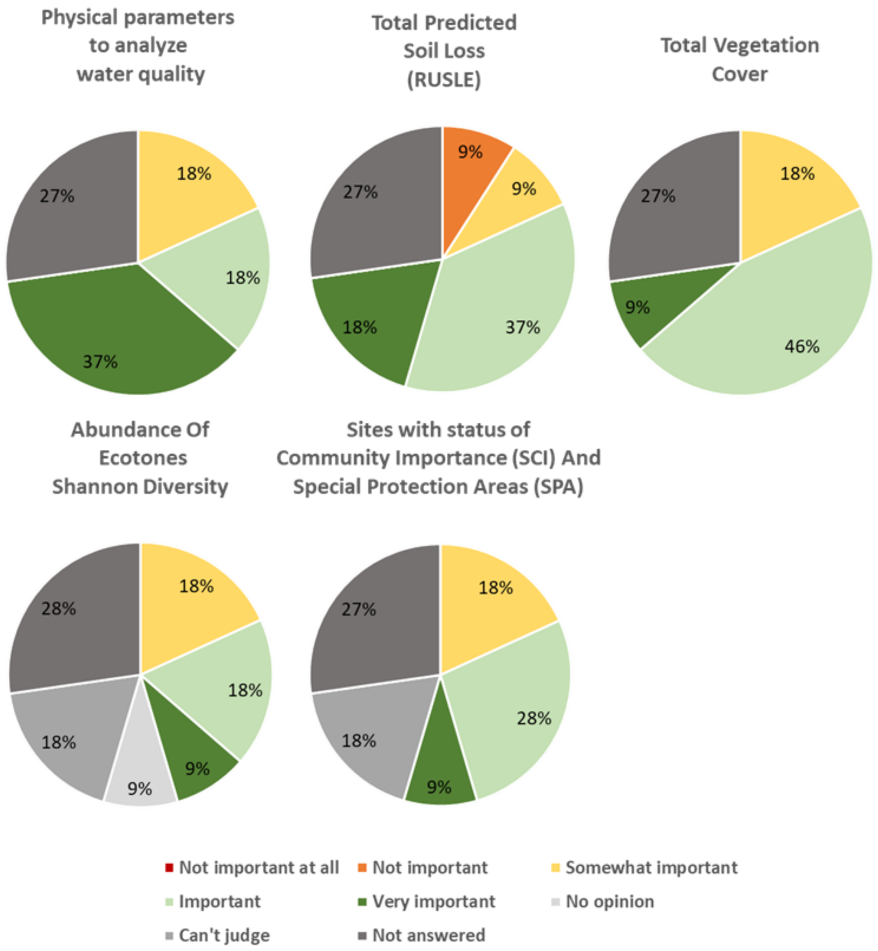


Figure 40. Usefulness of indicators for assessing NBS - Environment & Ecosystems ambit

<u>Indicators for the Society ambit</u>

The policy set up is considered the most important indicator (73% of the reviewees estimates it very important/important). At the contrary, visitor number indicators are considered less important (only 27% of the reviewees considers it very important/important).

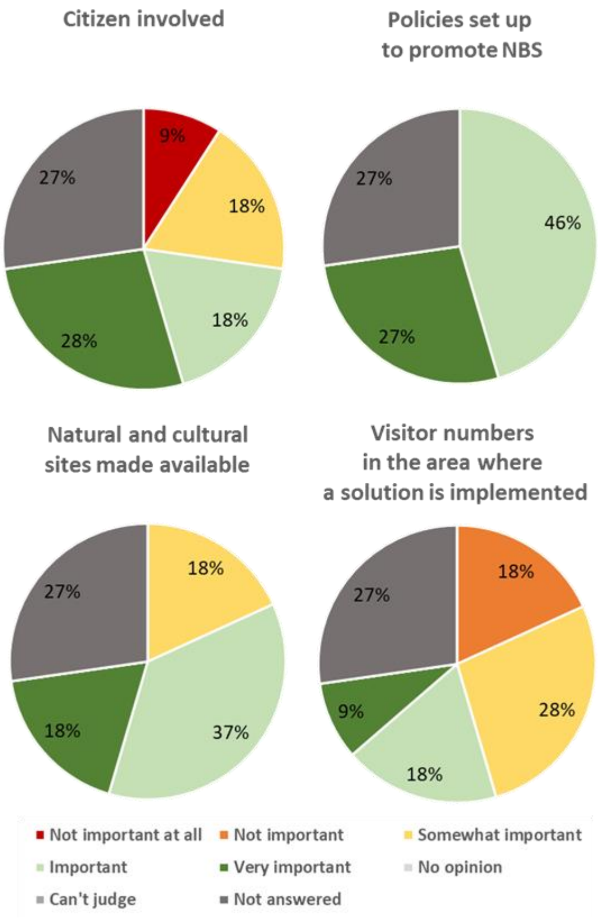


Figure 41. Usefulness of indicators for assessing NBS - Society ambit

<u>Indicators for the Local Economy ambit</u>

The rural productivity index is considered the most important (55% of the reviewees considers it very important / important), followed by the number of jobs created (45%). The touristic attractiveness enhanced indicator is not judging as a very important indicator (only 36% of the persons questioned considers it as an important indicator).

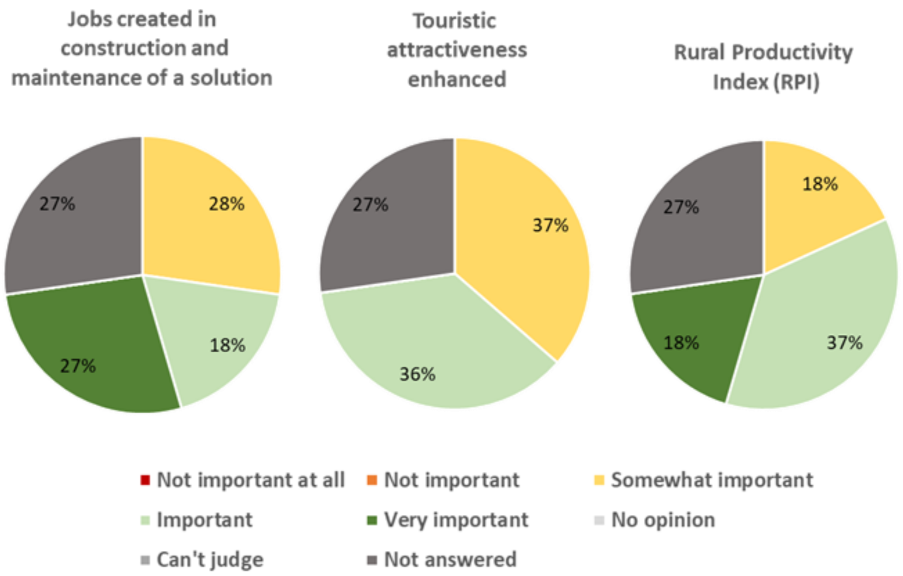


Figure 42. Usefulness of indicators for assessing NBS - Local economy ambit

5.4.4 Considerations for use and confidentiality of indicator data

As for the previous question, it is noticeable that 27% of the reviewees doesn't answer to this question. The following diagrams indicate whether, according to the interviewees, the measured indicators for risk reduction ambit should be shared as public information to promote the NBS.

All the reviewees that answer to the question agree on the publication of the volume of eroded material indicator. Concerning the two other indicators, the majority of the reviewees agree on its publication (between 55% and 64%).

<u>Indicators for the Risk Reduction ambit</u>

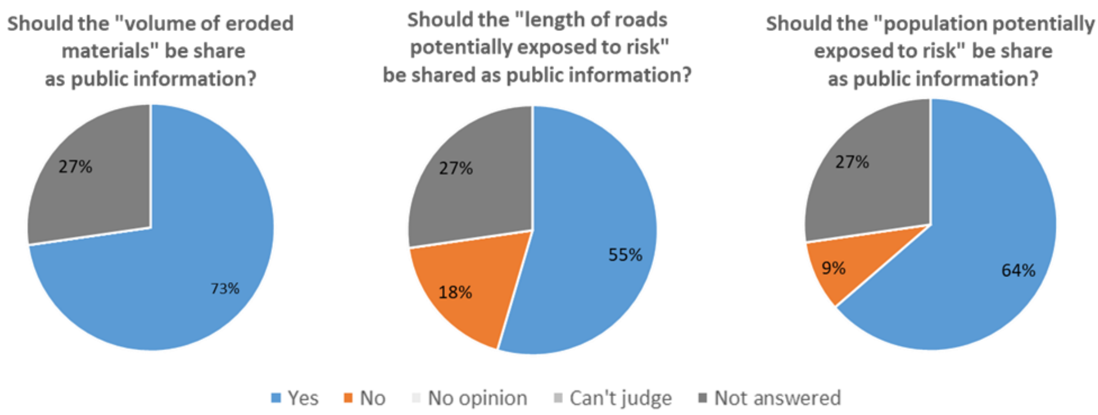


Figure 43. Sharing public information on the assessment of indicators from Risk Reduction ambit

Indicators for the Technical & Feasibility ambit

The following diagrams indicate whether, according to the interviewees, the measured indicators for Technical & Feasibility aspects ambit should be shared as public information to promote the NBS.

All the reviewees that answer to the question agree on the publication of the initial and maintenance costs indicators. 64% of the reviewees agree also on the material used for NBS implementation.

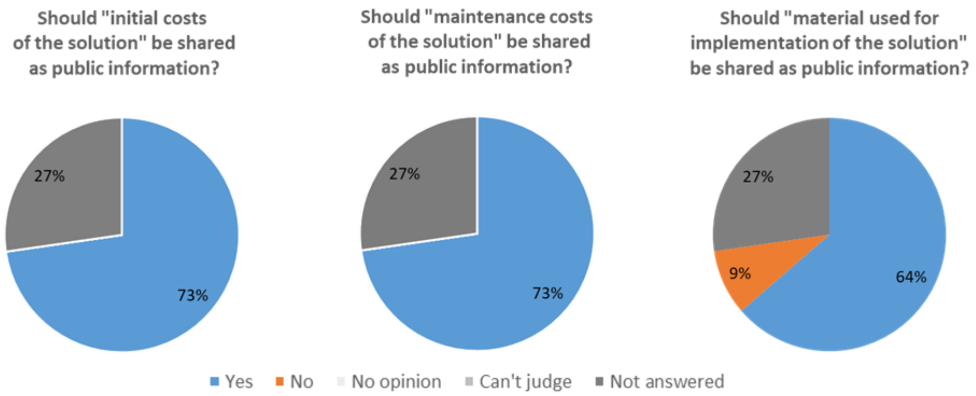


Figure 44. Sharing public information on the assessment of indicators from Technical & Feasibility aspects ambit

Indicators for the Environment & Ecosystems ambit

The following diagrams indicate whether, according to the interviewees, the measured indicators for Environment & Ecosystems aspects ambit should be shared as public information to promote the NBS. Regarding this ambit, it is noticeable that more persons don't answer to this question (between 27% and 45%).

The interviewees consider that the following need to be published: physical parameters (64%), total vegetation cover (55%) and and sites with status indicators (55%). Concerning the total predicted soil loss, only 37% of interviewees agrees on publishing the results.

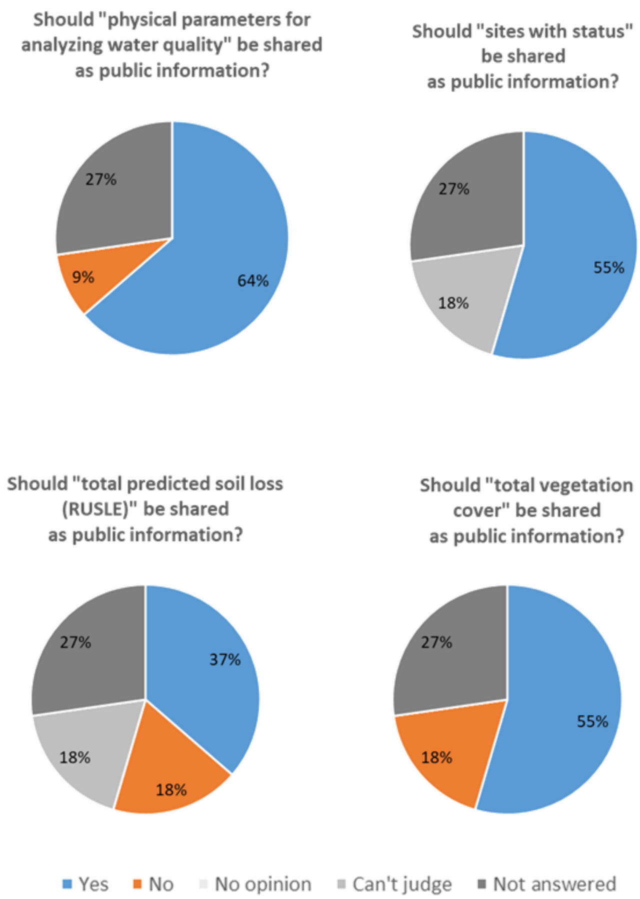


Figure 45. Sharing public information on the assessment of indicators from Environment & Ecosystems ambit

Indicators for the Society ambit

The following diagrams indicate whether, according to the interviewees, the measured indicators for Society ambit should be shared as public information to promote the NBS. All the reviewees that answer to the question agree on the publication of the number of visitors, policies set up and sites made available information. 64% of the reviewees agree also on the citizen involved information.

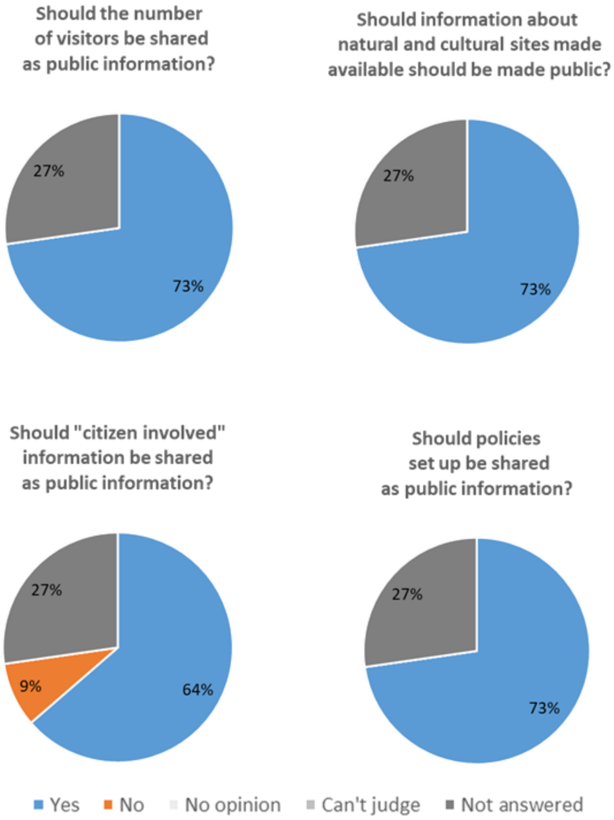


Figure 46. Sharing public information on the assessment of indicators from Society ambit

Indicators for the Local Economy ambit

The following diagrams indicate whether, according to the interviewees, the measured indicators for Local economy ambit should be shared as public information to promote the NBS.

All the reviewees that answer to the question agree on the publication of information concerning the jobs created and the touristic attractiveness.

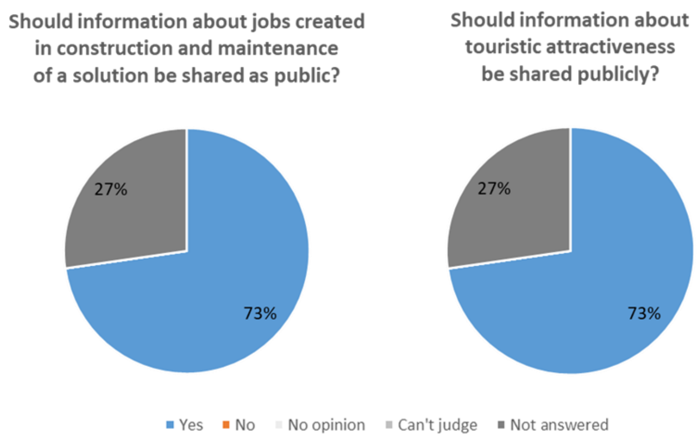


Figure 47. Sharing public information on the assessment of indicators from Local economy ambit

5.4.5 Appropriate methods for assessing indicators

In the following questions, it is noticeable a significant percentage of interviewees doesn't answer to the questions (between 27% and 50%, depending on the questions).

Technologies to measure or assess the volume of eroded materials
It should be noted that 36% of the reviewees doesn't answer to this question.

The results are quite contrasting, as: Airborne lidar (twice per year) and photography using drones are considered very suitable (by 55% of the reviewees); but conversely, only 18% of the reviewees considers lidar more frequently acquired as adapted, and 18% of the reviewees considers lidar not suitable. The acquisition frequency is therefore a significant feature according to the reviewees. Terrestrial lidar is not considered as adequate technology (only 27% of the reviewees considers it as appropriate).

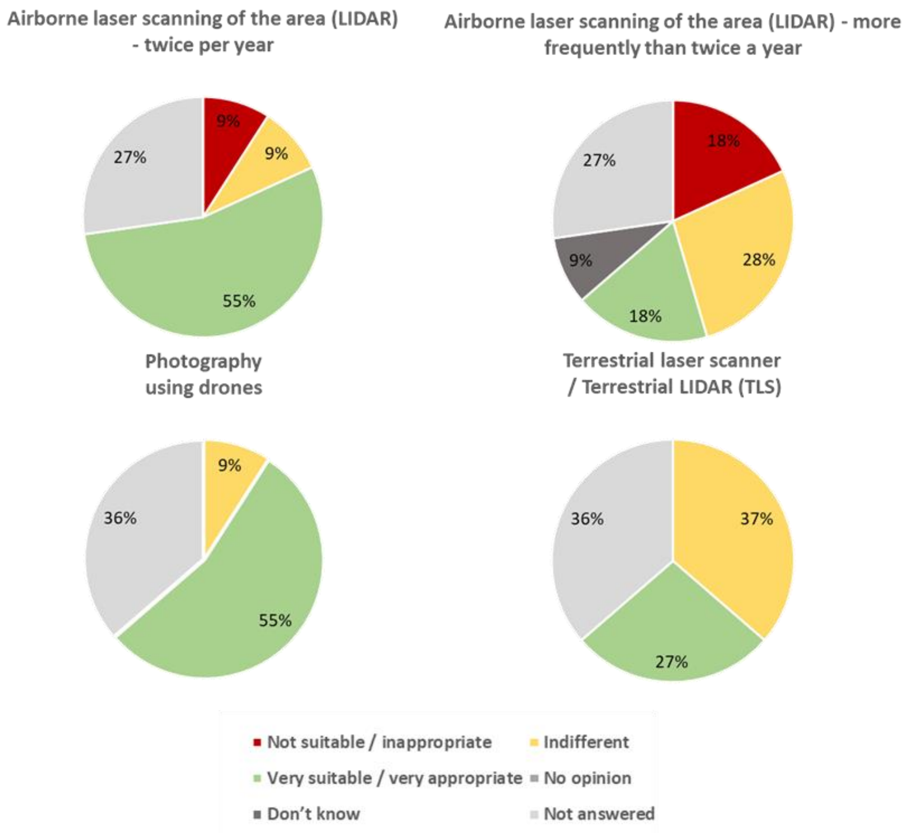


Figure 48. Suitability of technologies to assess/measure the volume of eroded materials

Assessing technical and economic feasibility
The most adapted method is ground-based inspections / survey by experts (70%). The other methods are also considered appropriate (40% agrees on that), even if 10% estimates that analysing public data is not adapted.

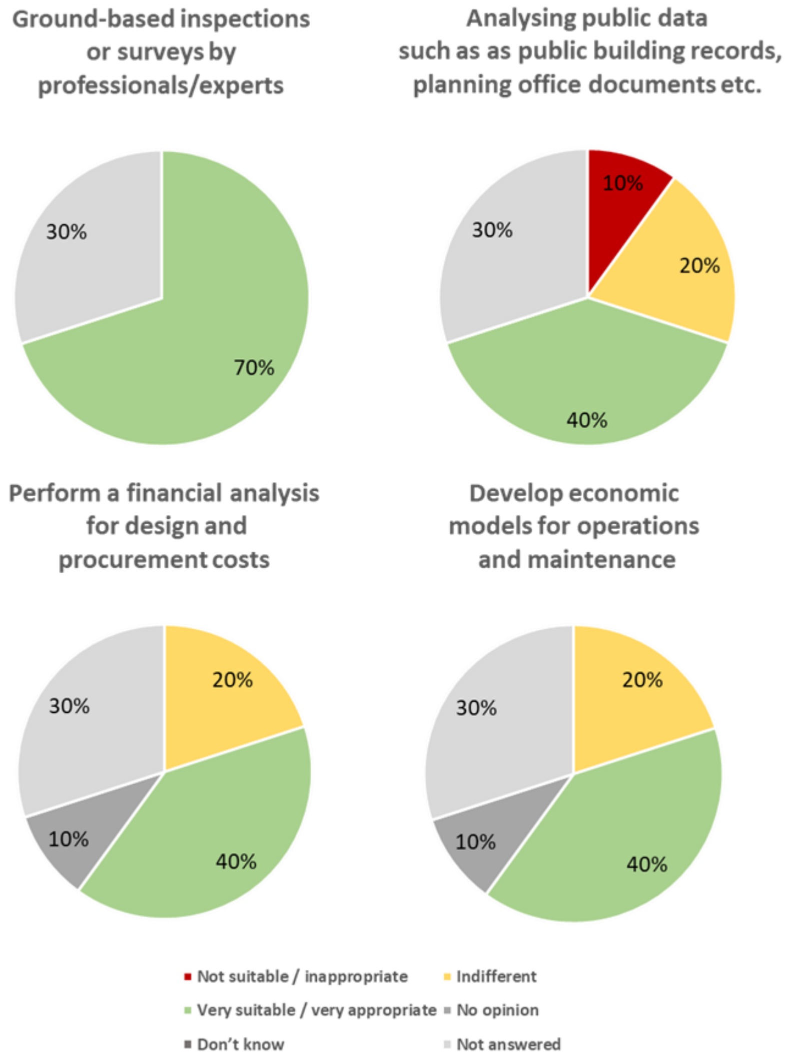


Figure 49. Suitability of methods for assessing technical and economic feasibility

Assessing environmental aspects (water, soil, biodiversity, vegetation and green infrastructure)

According to 80% of the interviewees, several technics are adapted for measuring environmental indicators. Analysing available data (reports etc.), ground-based inspections or surveys by professionals/experts, sampling (of soil, water, fauna and flora), as well as regional surveys (using photography, satellite images…) are very suitable according.

Specific counts of species and theoretical analysis using scientific modelling methods are also suitable (50%). Finally, only Microscopic analysis may not be appropriate (20% considers it as not appropriate).

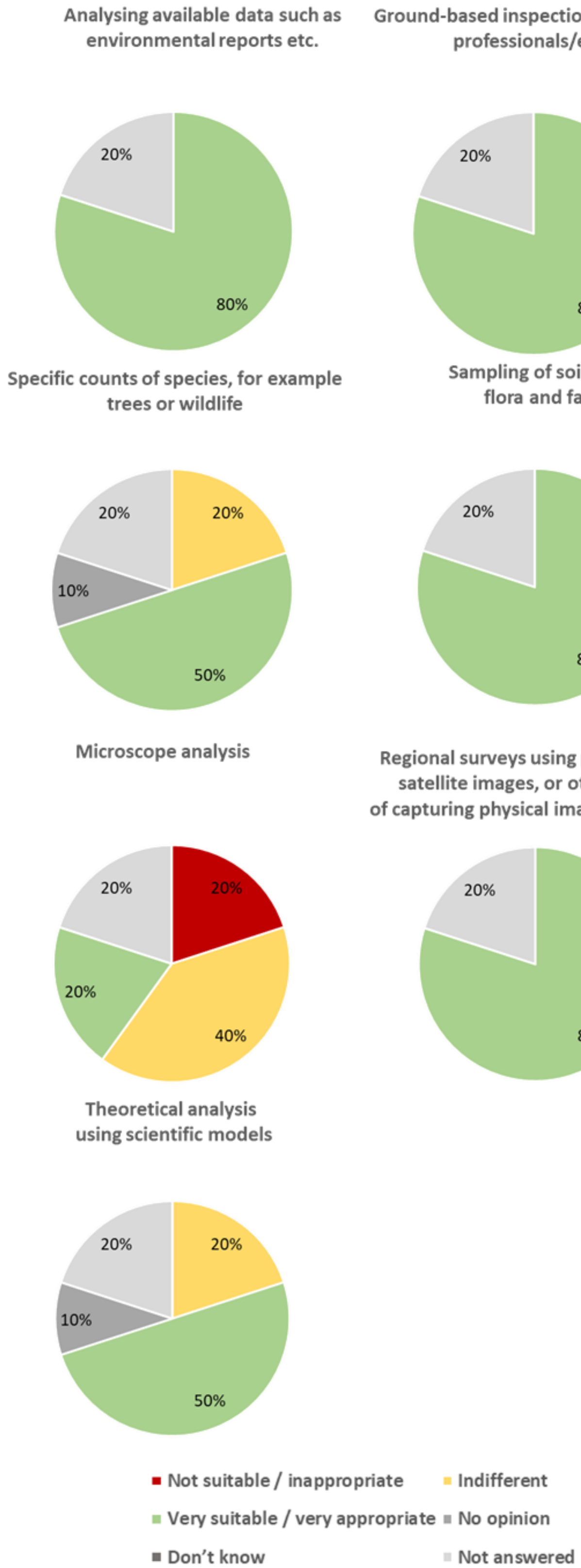


Figure 50. Suitability of methods for assessing environmental aspects

Assessing the involvement of citizens.

The most adequate method is to count the number of participants at events, according to 70% of the reviewees, followed by the membership numbers in groups on social media and counting the 'likes' or reactions in social media methods (between 30 and 40% of the reviewees agrees on these methods). At the contrary, counting participation levels in surveys provides an indifferent opinion (60%).

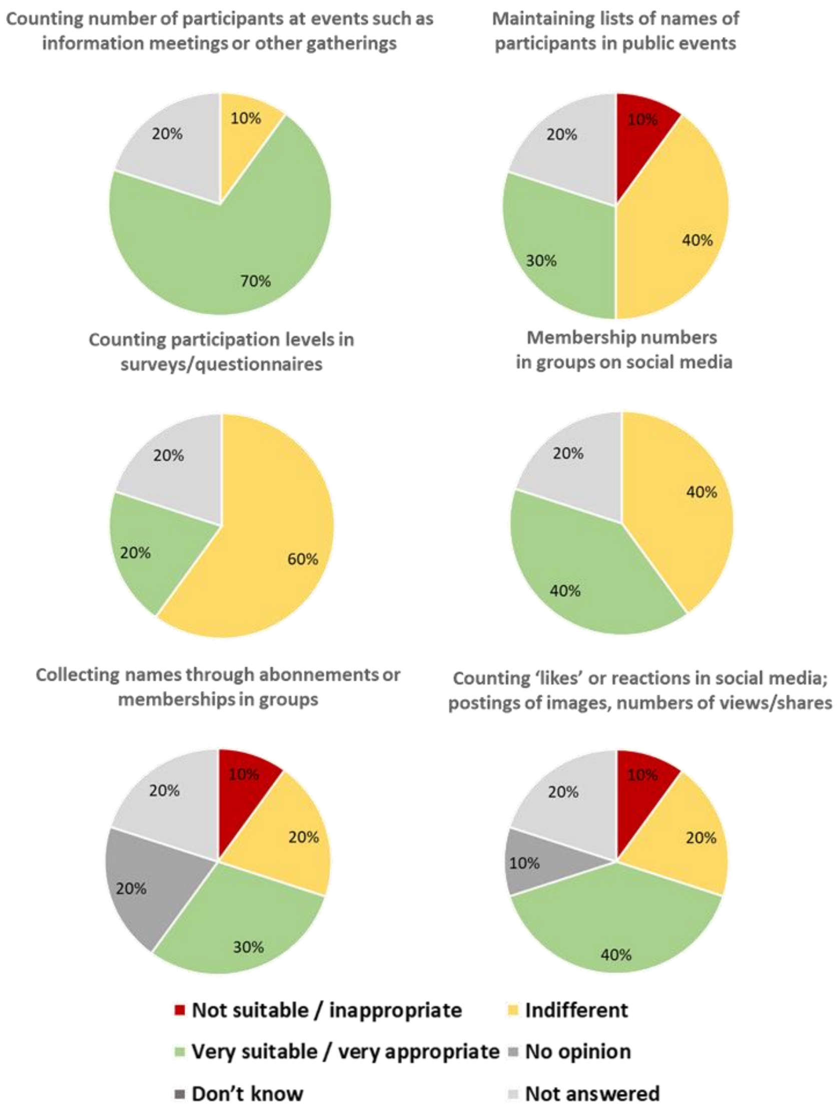


Figure 51. Suitability of methods for assessing the involvement of citizens

Assessing the policies and promoting the use of NBS

All three of the methods are considered suitable: Review public documents (60%), Consultation of municipal land use plans (70%), and Consultation of river basin authorities plans (80%).

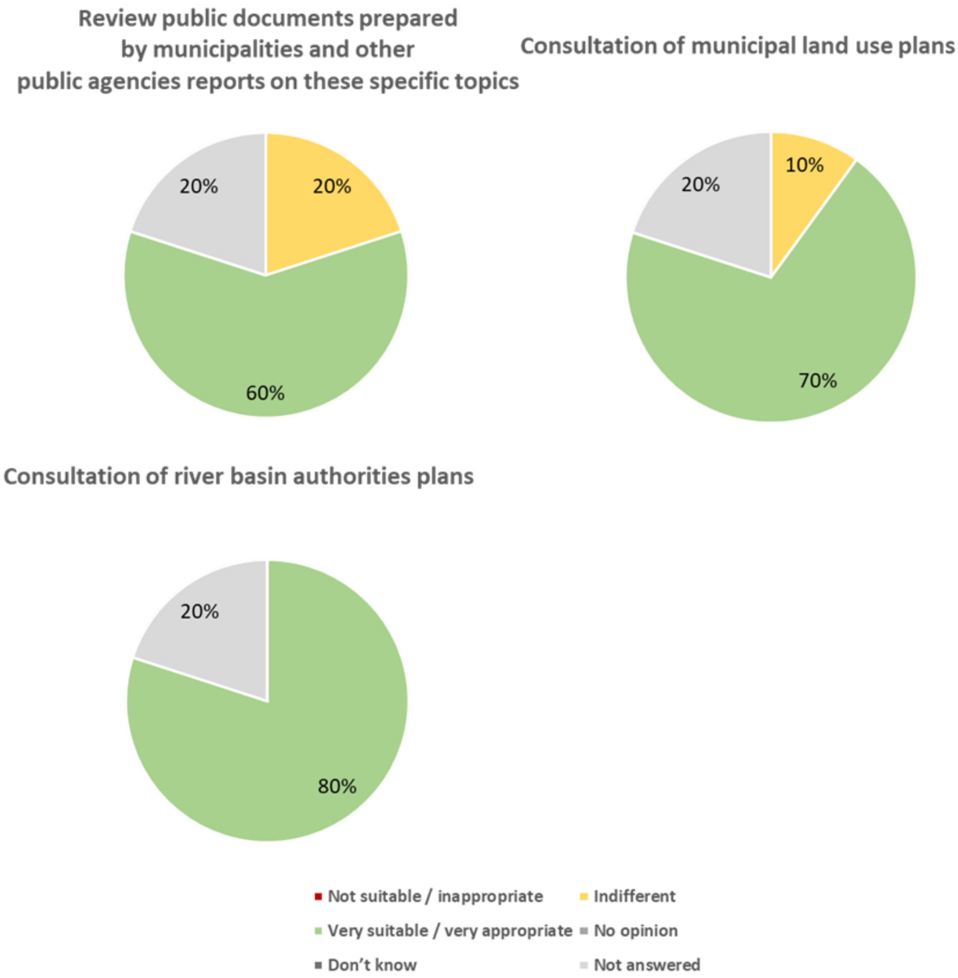


Figure 52. Suitability of methods for assessing policies and promoting NBS

<u>Assessing the creation of jobs</u>

It is noticeable that 40% of the people questioned doesn't provide any answers.

The method that seems to provide satisfactory results concerns the statistical analysis based on official databases (50%). The three other are appropriate according to only 20% (with economic models, literature reviews) or 30% (with census data) of the interviewees.

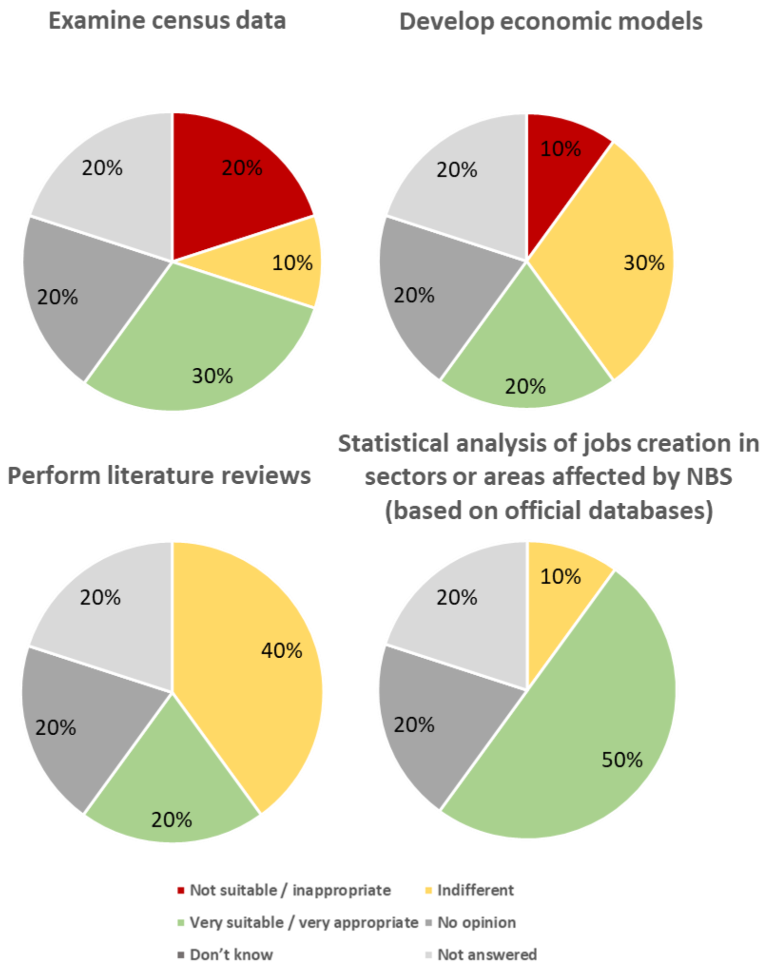


Figure 53. Suitability of methods for assessing the creation of jobs

<u>Assessing impacts on tourism</u>

It should be borne in mind that between 40% and 50% of the reviewees doesn't provide any answers. Several methods are estimated as adequate, such as the analysis of geolocation of posts on social media (60%), the consultation of data provided by official databases (50%), indirect data (amount of solid waste, number of houses available for vacation, tourism tax…) (50%).

At the contrary, the method based on the surveillance cameras and time-lapse video recording is not considered appropriate (only 20% of the interviews considers it as adequate).

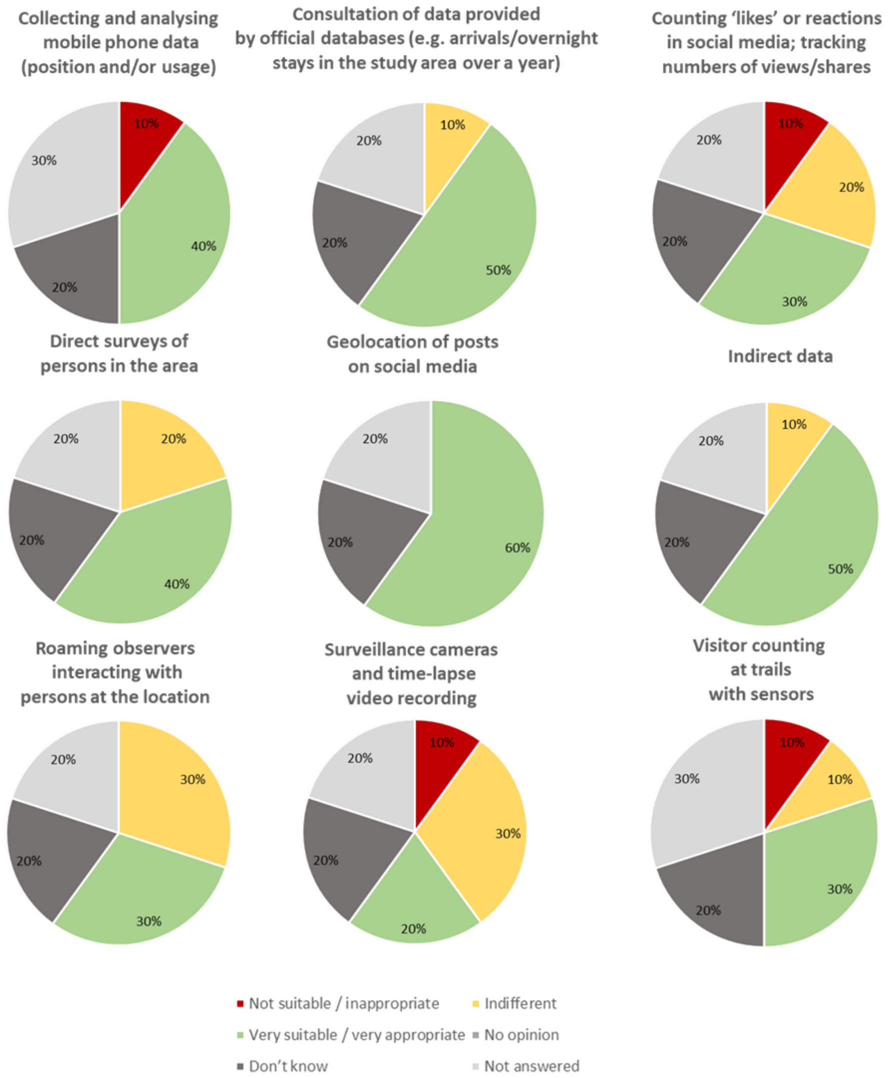


Figure 54. Suitability of methods for assessing the improvement of tourism

5.5 Summary and experience

5.5.1 Findings from the LL for Serchio River Basin

As a summary, the answers of the responders to this questionnaire reveal their approval, their interest to the applied approach in this study, and their wish of its promotion. Indeed, concerning the usefulness of indicators for assessing NBS, it appears that, in general, for all the 5 ambits, at least one of the proposed indicators is considered useful. The most valuable indicators, according to the interviewees, are the initial cost of NBS, the maintenance costs, as well as the policy set up.

Moreover, in a large majority, the interviewees agree on sharing measurements as public information to promote the NBS, even if, regarding some ambit (in particular Environment & Ecosystems aspects), it is noticeable that some persons don't answer this question. That means that the interviewees are sensitive to the promotion of the NBS to the public.

Concerning the suitability to assess indicators, different technologies or methods are proposed for measuring the indicators. In general, for some indicators, a strong consensus is achieved with all propositions, as it is the case for instance for several technics considered adapted for measuring environmental or for assessing policies and for promoting the NBS.

For some others, one technic stands out among the others; indeed, for assessing technical and economic feasibility, the most adapted method is ground-based inspections / survey by experts. Another example concerns the involvement of citizens, for which the most adequate method is to count the number of participants at events.

Finally, for some other indicators, different technologies or methods are suitable, as it is the case for measuring the volume of eroded materials, or for assessing improvements to tourism.

It should be borne in mind that between 40% and 50% of the reviewees doesn't provide any answers.

5.5.2 Experiences from applying the LL methodology

Due to the challanges of the pandemic it was necessary to adapt the implementation of the LL methodology to accomodate online processes. The approach selected was to try to implement this as an online survey distributed to stakeholders. This approach was tested on one of the demonstration case sites. The general experience is that this approach was well received by the stakeholders and the overall rate of response was atisfying and encouraging.

The main difficulty encountered was related to the complexity of data we wanted to submit to stakeholders. The survey focused on indicators, however there are many indicators and most of them concern technical subjects. Including the full set of indicators would result in an excessively long survey, which was believed would result in recipients loosing motiviation and not completing the survey.

To address this, a subset of the indicators was selected for the survey and the descriptive terminology for these indicators was simplified. The indicators were selected by a subjective evaluation of the most relevant indcator(s) per ambit, where the selected indicators were thought to be the most tightly linked indicators to the subjects or topics that the PHUSICOS project is addressing. Selecting the indicators was found to be rather difficult, and clearly there is room for improvement in how this selection process might be done.

The survey text was developed and implemented in a commercial online survey software. Although only a subset of indicators were used, the survey was still relatively lengthy and complicated. The survey was distributed to relevant stakeholders without difficulty, and within 2 weeks quite a few responses were received. Statistics of the survey show that 10 participants completed the full survey out of 15 recipients who started answering it, giving a completion rate of 67%. This rate may in the future be improved by shortening the questionnaire and by further simplifying the vocabulary, as discussed by Frippiat and Marquis, 2010.

6 IMPLEMENTING MONITORING NETWORKS

The evaluation of NBS performance must include aspects of both short and long term performance as well as the effects of co-benefits to convince and foster the use of them (Rizvi et al., 2015; Runhaar et al., 2018). The monitoring network needs to be developed to serve specific purposes - what needs to be monitored, how will the data be accessed, for what purpose will it be used, who needs the data, what are their specific requirements for accuracy, frequency of measurement, spatial density etc. McVittie et al. (2018) indicate that monitoring and research are essential priorities.

Monitoring will address 'engineering' monitoring, e.g. physical parameters, as well as 'non-engineering' indicators, like population use patterns, or economic effects. Moreover, it will cover both quantitative and qualitative measurements of some indicators. Particularly challenging are qualitative variables that are not possible to quantitatively measure, for example improving aesthetics; or are difficult to measure using simple sensors, for example increasing biodiversity.

The monitoring activities address different needs, e.g. baseline, longterm operations and early warning:

- Baseline monitoring - this addresses aspects of the site (location) prior to the implementation of the NBS. Monitoring will focus on 'indicators' for the NBS implementation. Some of the indicators may be necessary for the initial NBS selection and implementation processes, other indicators may be 'reference' values to which future values of the same indicators will be compared, e.g. the start values needed to evaluate *changes* brought about by implementing the NBS.
- Operational (longterm) monitoring - this addresses aspects of the site (location) during the lifetime of the NBS. These indicators are used to assess both the operational conditions of the NBS, but also the impacts or effects of the NBS both in terms of direct benefits and co-benefits. These may often be compared to baseline parameters to assess change. As an example: a direct benefit of an NBS might be to reduced flooding, a co-benefit might be increased local tourism by creating walkways and bike paths. Indicators may be related to area flooded, or counts of numbers of visitors.
- Early Warning - This is an activity needed for the PHUSICOS demonstrations as the primary functional purpose of the NBS implementations are to mitigate hazards. In an Early Warning activity, indicators or parameters relevant for assessing risk or danger and which are variable over time are monitored. These indicators are evaluated against threshold values (indicating imminent risk) and

trigger an appropriate response. An example may be an NBS implementation to control flooding, where an indicator measuring maximum water height may be used as an early warning for potential failure of the NBS during heavy storms.

Monitoring needs and specifications will vary, for example the duration of monitoring needed to give representative measurements, the frequency of measurements required, or even the accuracy or precision of the measurements. For example, indicators related to weather may require frequent measurement, whereas indicators related to biodiversity perhaps need only seasonal or annual updating.

Monitoring activities must be designed to meet needs, and the best source for defining specific monitoring needs are the stakeholders who want the data. The Living Labs methodology is a viable approach to ensure this. Different stakeholder groups may have differing needs; these needs may also change depending on the phase of the project implementation (for example baseline versus long-term monitoring).

The specific application of an Early Warning System will also carry specific needs, for example, the protection of people (considering different conditions of age, disabilities, awareness) and the safeguard of cultural and economic resources (safeguarding flocks and herds, loss of crops and other livelihoods, damage to infrastructure).

Another essential consideration is adequate knowledge on the phenomenon to be measured, through hazard and risk pre-investigations. Furthermore, the update of the phenomenon knowledge may imply an update of the monitoring system if necessary.

6.1 General features & recommendations

For designing a monitoring system, and particularly for a system meant for an early warning application, some general features and recommendations can be made. Some are exposed below, from Michoud et al., 2013.

Firstly, a good monitoring network is characterized by:

1. simplicity;
2. robustness;
3. presence of multiple sensors;
4. power and communication lines backups.

The following characteristics are also important for the choice of instrumentation:

1. Appropriateness of the sensor for measuring the phenomenon
2. high life expectancy;
3. robustness;
4. price;
5. level of real-time data;
6. noise level of the sensors.

The redundancy of power supply backups is necessary for a reliable monitoring system, as are facilities for remote data access and/or transmission of data.

Redundancy of sensors are important as systems may be in harsh conditions and therefore it is difficult to repair or maintain components. Damage may occur due to natural causes (heavy rainfall, ice, thick snow cover, avalanches, wind, etc.) but they may also be subject to human activity causing damage or disruption. It also permits to discriminate unwanted false alarms coming from large noise or one defective sensor.

As technology is undergoing rapid development, it may be necessary to accommodate updating or replacement of components in a system. These costs need to be considered when evaluating operation and maintenance costs. Continuity of funding over several (or many) years to maintain systems may be a challenge.

When implementing automated alarm systems, it is important to consider technical limitations of the system when establishing threshold or data evaluation protocols. The nature of the phenomenon measured must also be considered, as the measurement needs may change over time and thus adaptive scenarios for thresholds may need to be considered. Threshold values for alarm messages should normally be based on the evaluation of more than one sensor for reliability. If multiple data are necessary to evaluate a scenario, each type of data required should include redundancy.

Finally, any monitoring system implementation requires clear definitions of roles and responsibilities.

6.2 Communication & Decision Making

Measuring indicators is only part of the overall monitoring scheme - we need also to communicate the data and assessments to interested parties. In the case of early warning systems, we need to develop trust in the local affected population and encourage appropriate behaviour of people in case of alert.

Initially the plans, needs and purpose of the monitoring system / early warning system need to be communicated to interested parties. There are many ways to achieve this, such as public meetings, reports, or websites with information. The public meetings are particularly interesting, as it permits to inform and consult local populations during and/or after every round of the decision-making process.

Collected data may be sensitive and complex data and finding the right communication level is difficult. Free and easy access to all data collected for anyone interested may not be a viable strategy. For example, some data may be difficult to interpret or may be easily misunderstood. System or sensor errors or failures might cause unnecessary concerns. However, lack of communication may also have the negative effect of making people suspicious that there is something to hide. Although not communicating the monitored data could make local people suspicious, incorrect readings could also lead to major misunderstandings and unnecessary concerns.

For an early warning monitoring system there are two vital considerations:

- Decision processes must be clearly and concisely defined
- The communication plan needs to be well constructed ensuring that the right information reaches the correct recipients and the appropriate times.

Tailored strategies for the decision-making process must be adopted depending on the sites. The design of decision-making processes should take care of legislation and cultural issues, as well as of the prerogatives of the involved agencies.

The execution of these strategies requires close collaboration between the operational units and local and/or regional authorities. Rigorous protocols must be established to clearly define the roles and responsibilities of each institution according to the alert levels. A flowchart can give an evident checklist reviewing necessary procedures.

The communication plan may require multiple information vectors: broadcast devices like radio, TV, sirens or SMS may be appropriate. Direct methods like door-to-door messaging by authorities may be another approach. Signalling devices, like traffic lights, beacons or physical barriers blocking paths or roadways may be another form of communication.

The communication plan should also include appropriate responses to communication received, for example the strategies for evacuation or mitigation for the hazard.

7 CONCLUSION

This deliverable provides guidelines and recommendations for detailed planning, procurement and deployment of monitoring systems of NBSs.

A guideline has been proposed, covering conceptual design considerations - essentially a working reference for organisations planning on implementing monitoring of NBSs. It implies a state of the art on new technologies that might be used within the monitoring system. The monitoring needs have then been defined for each ambit, providing for each indicator the methods, sensors, and data that can used. These methods, sensors and data are then described, highlighting the advantages and drawbacks of them.

The second part of the deliverable focuses on the application of the living labs concept, by investigating how stakeholders and experts may work together in a living labs approach to refine design concepts and general recommendations into detailed monitoring system designs in preparation for procurement and implementation. The methodology has been illustrated through the application in Serchio case study. For that, a tailored online questionnaire has been created, filled by stakeholders, and the interpretation has been presented. This methodology will be applied to all the sites described within this report, with some little improvements that are proposed in the report.

As a summary, the answers of the responders to this questionnaire reveal their approval, their interest to the applied approach in this study, and their wish of its promotion. Indeed, concerning the usefulness of indicators for assessing NBS, it appears that, in general, for all the 5 ambits, at least one of the proposed indicators is considered useful. Moreover, in a large majority, the interviewees agree on sharing measurements as public information to promote the NBS. That means that the interviewees are sensitive to the promotion of the NBS to the public.

Concerning the suitability to assess indicators, different technologies or methods are proposed for measuring the indicators. For several indicators, a strong consensus is achieved with all proposals; for some others, one technic stands out among the others, while, for some other indicators, different technologies or methods are suitable.

Finally, some general features and recommendations are proposed for implementing a monitoring networks. For designing an early warning monitoring system, some general features and recommendations can be made.

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